

HZ production at 3 TeV CLIC

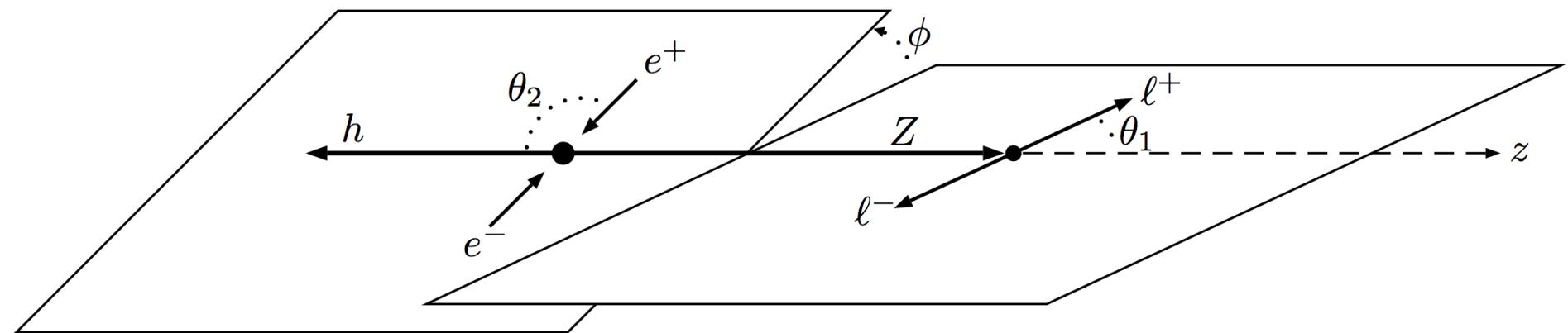
Matthias Weber (CERN)

Motivation

ZH angular observables

CLIC can constrain or observe anomalous contributions in ZH events

- Deviations from SM predictions have been studied in dimension-6 SMEFT in the CLIC physics potential report for events with leptonic Z decays (extended from the analysis in JHEP 03 (2016) 050 and JHEP 09 (2017) 014)
- Previous studies rely on leptonic Z, hadronic Z decays offer far larger statistics, with a cost of larger amount of background → investigate HZ with $Z \rightarrow q\bar{q}$



θ_2 angle between H and e^+ in e^+e^- restframe (leading jet and e^+)

θ_1 angle between Z and positive charged quark and original Z direction (in e^+e^-) in Z restframe (second leading jet, subjet with assigned positive quark)

Φ angle between the two planes

Definition: Angular Variables

$$\begin{aligned}
\mathcal{A}_{\theta_1} &= \frac{1}{\sigma} \int_{-1}^1 d \cos \theta_1 \operatorname{sgn}(\cos(2\theta_1)) \frac{d\sigma}{d \cos \theta_1} \\
&= 1 - \frac{5}{2\sqrt{2}} + \frac{3J_1}{\sqrt{2}(4J_1 + J_2)} \\
\mathcal{A}_\phi^{(1)} &= \frac{1}{\sigma} \int_0^{2\pi} d\phi \operatorname{sgn}(\sin \phi) \frac{d\sigma}{d\phi} = \frac{9\pi}{32} \frac{J_4}{4J_1 + J_2} \\
\mathcal{A}_\phi^{(2)} &= \frac{1}{\sigma} \int_0^{2\pi} d\phi \operatorname{sgn}(\sin(2\phi)) \frac{d\sigma}{d\phi} = \frac{2}{\pi} \frac{J_8}{4J_1 + J_2} \\
\mathcal{A}_\phi^{(3)} &= \frac{1}{\sigma} \int_0^{2\pi} d\phi \operatorname{sgn}(\cos \phi) \frac{d\sigma}{d\phi} = \frac{9\pi}{32} \frac{J_6}{4J_1 + J_2} \\
\mathcal{A}_\phi^{(4)} &= \frac{1}{\sigma} \int_0^{2\pi} d\phi \operatorname{sgn}(\cos(2\phi)) \frac{d\sigma}{d\phi} = \frac{2}{\pi} \frac{J_9}{4J_1 + J_2} \\
\mathcal{A}_{c\theta_1, c\theta_2} &= \frac{1}{\sigma} \int_{-1}^1 d \cos \theta_1 \operatorname{sgn}(\cos \theta_1) \int_{-1}^1 d \cos \theta_2 \operatorname{sgn}(\cos \theta_2) \frac{d^2\sigma}{d \cos \theta_1 d \cos \theta_2} \\
&= \frac{9}{16} \frac{J_3}{4J_1 + J_2}.
\end{aligned}$$

Signal Reconstruction

Strategy & Objects

$HZ \rightarrow bb\ qq$ at $\sqrt{s}_{\text{eff}} > 2500$ GeV characterised by two high-energy boosted fat jets, back-to-back in azimuth, each jet contains two sub-jets

Excellent jet mass resolution helps to discriminate between signal and background signatures

Jets defined using VLC algorithm with $\beta=\gamma=1.0$, run in exclusive mode with $R=0.7$ with $n_{\text{jets}}=2$

→ tight timing and p_T selection applied on particle flow objects for jet clustering

Check for isolated leptons with $E > 10$ GeV

Requirement: relative isolation $\text{relIso} < 0.10$ within a cone of 10 degrees

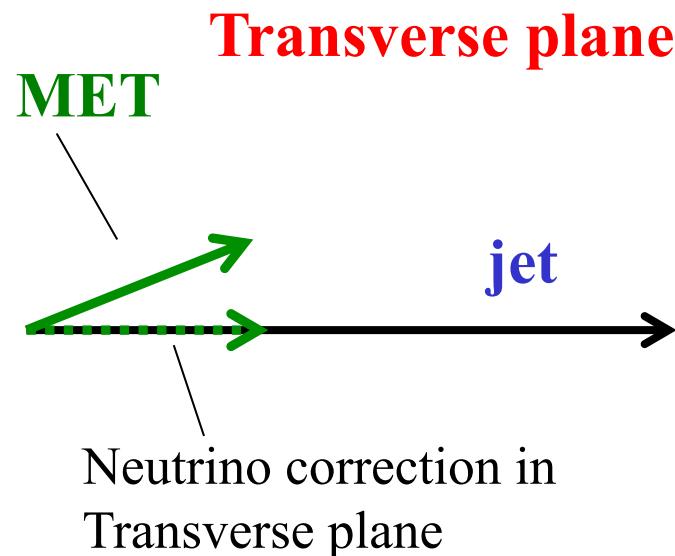
→ lepton veto in event selection

Ordering jets by masses ($j_1 > m(j_2)$), treat j_1 as H jet, j_2 as Z jet

Mass Recovery using missing transverse energy

Idea: neutrinos appear in decays of B-hadrons, typically in boosted regime direction aligned with corresponding jet direction

Use missing transverse energy (MET), calculated from all TightSelectedPFOs in event:
→ check if MET in same hemisphere of jet in question
→ project MET onto jet transverse momentum vector, increases jet transverse momentum vector by factor $f > 1$, apply factor f to z-component of jet momentum

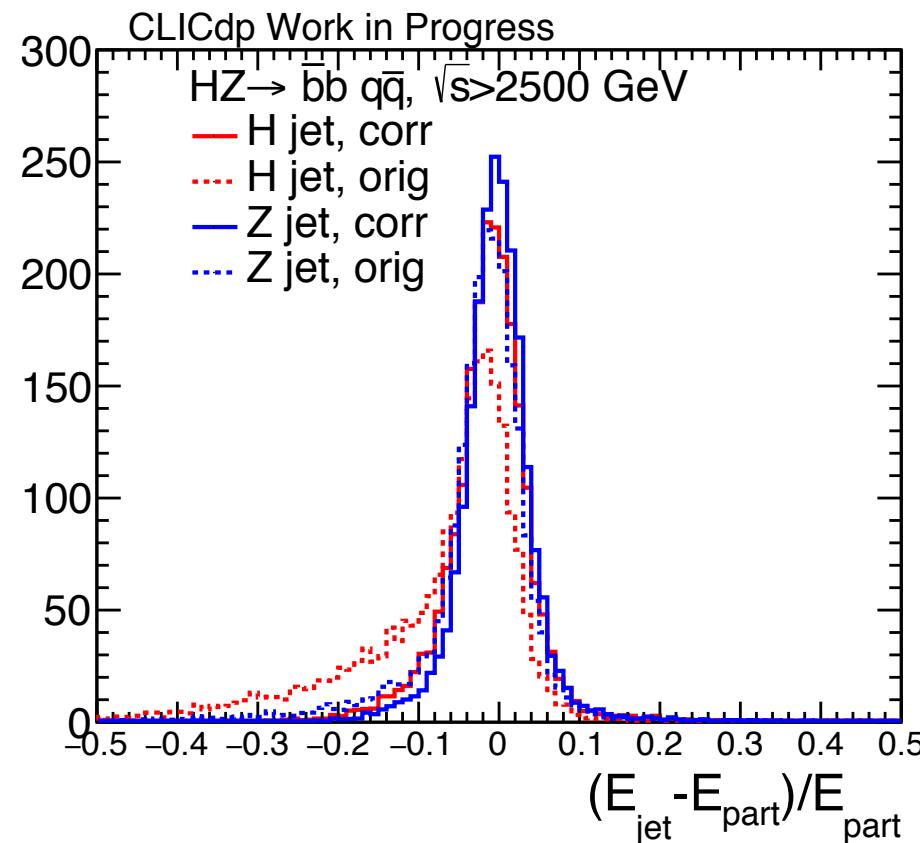
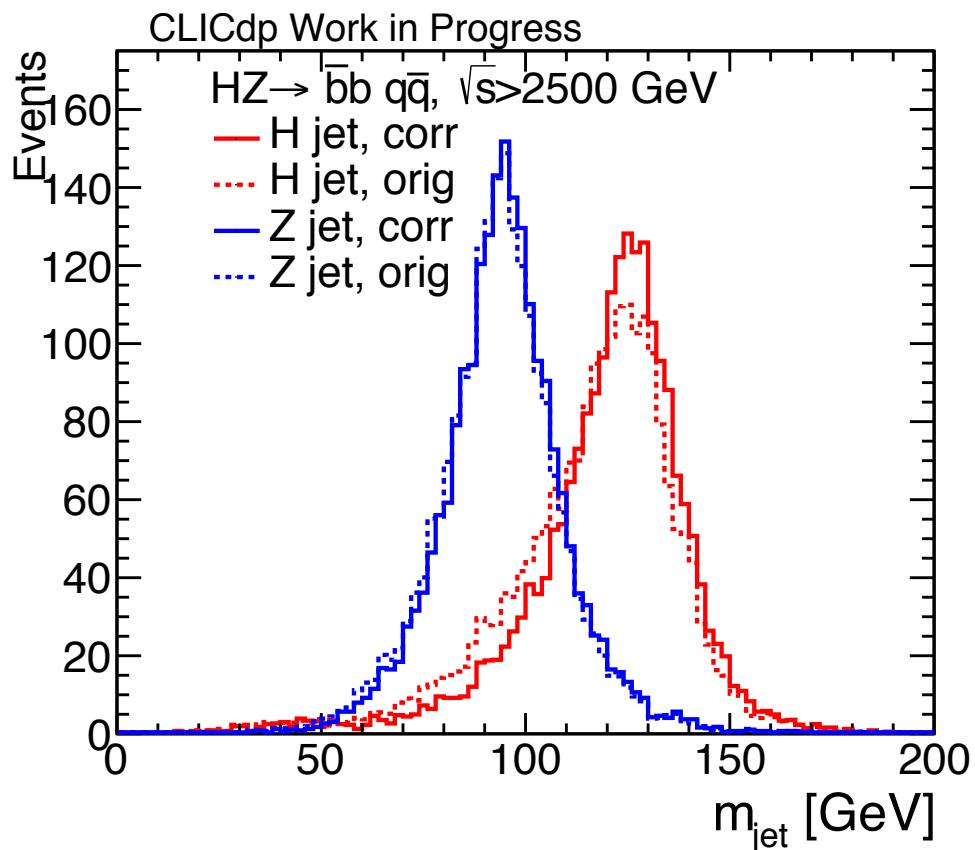


add $(f-1)*p_{jet}$ to original jet energy, assumes massless particle as origin of MET:
 $E' = E + (f-1)*p_{jet}$

Mass and energy of jets after met correction

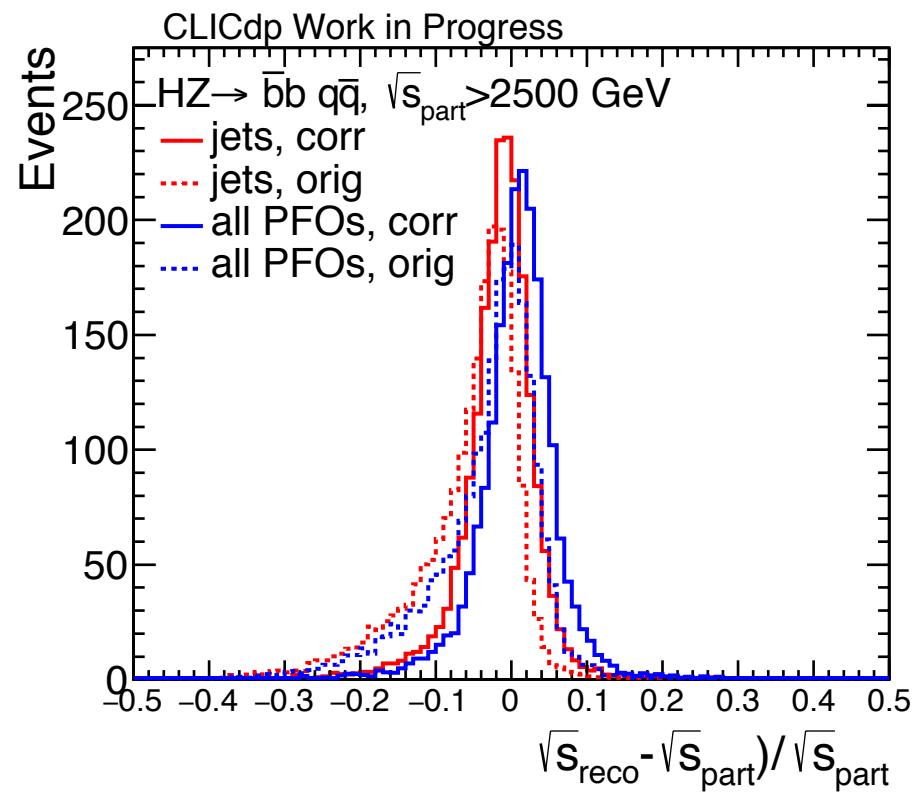
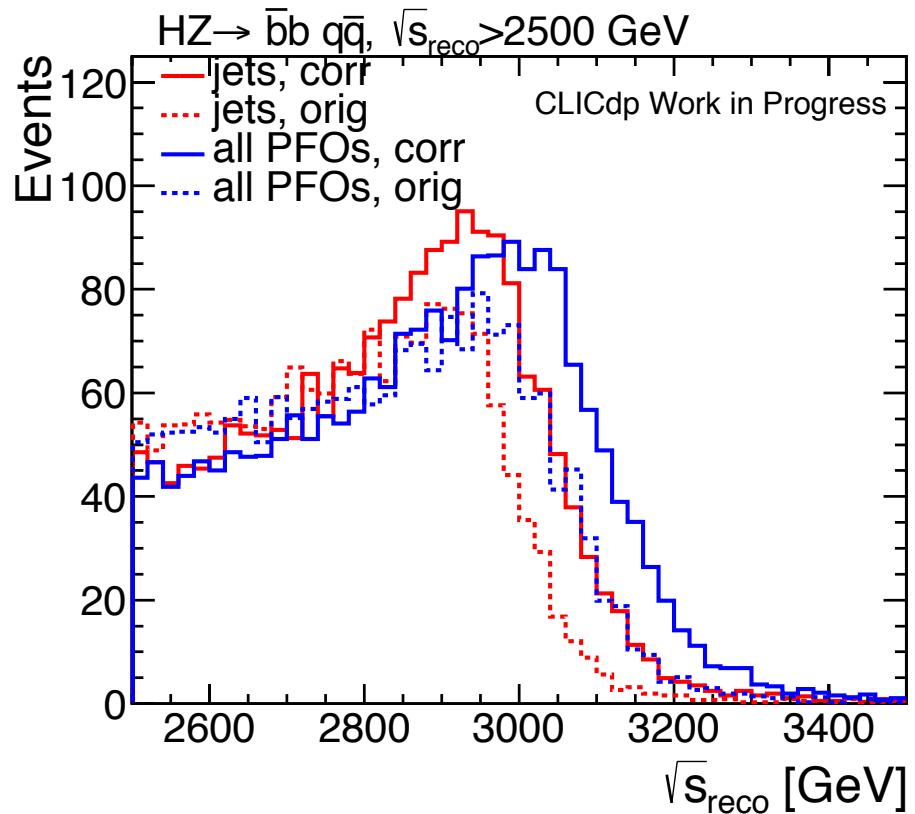


Peak of jet mass and tail of mass distribution to lower values reduced, particularly for jet matched to H, energy better reconstructed as well
→ MET correction leads to improved \sqrt{s} as well



\sqrt{s} after MET correction

Best reconstruction of \sqrt{s} using both leading jets, using all tight selected PFOs leads to slight bias to larger \sqrt{s} values



Selection of positive charged quark



Use jet charge of subjets of second reconstructed jet (lower mass) as handle on quark charge, five different selections

$$Q^\kappa = \sum_i \left(\frac{E_i}{E_{\text{jet}}} \right)^\kappa Q_i$$

1. Consider subjet with larger absolute jet charge value
2. Consider subjet with largest energy
3. Give preference to subjet with largest charge multiplicity, if both subjets have same multiplicity, use criteria 1
4. Consider subjet with largest charged energy fraction
5. Consider subjet with largest charged energy

→ if jet charge of selected subjet < 0, use the other subjet direction as positive charge quark direction

→ if jet charge of selected subjet > 0, use subjet direction as positive quark direction

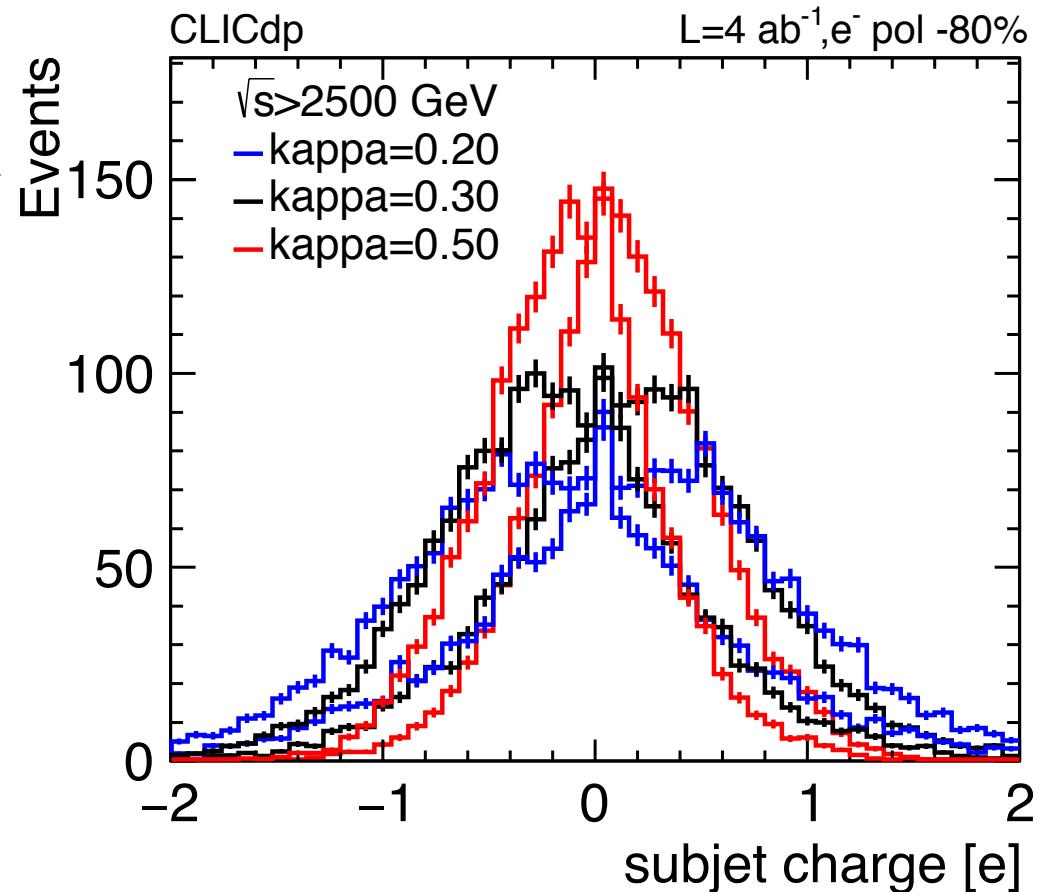
Subjet Charge: different kappa values

Try to differentiate between negatively and positively charged subjet:

→ study different kappa parameters to find out which one seems most discriminant

Angular match of subjets from second leading mass jet to positive and negative quarks from Z

Study overlap between subjet charge distribution of positive and negative quark matched reconstructed jets



Studied κ values between 0.15 and 1.0: criteria: least overlap of events

→ $\kappa=0.30$ provides largest discrimination

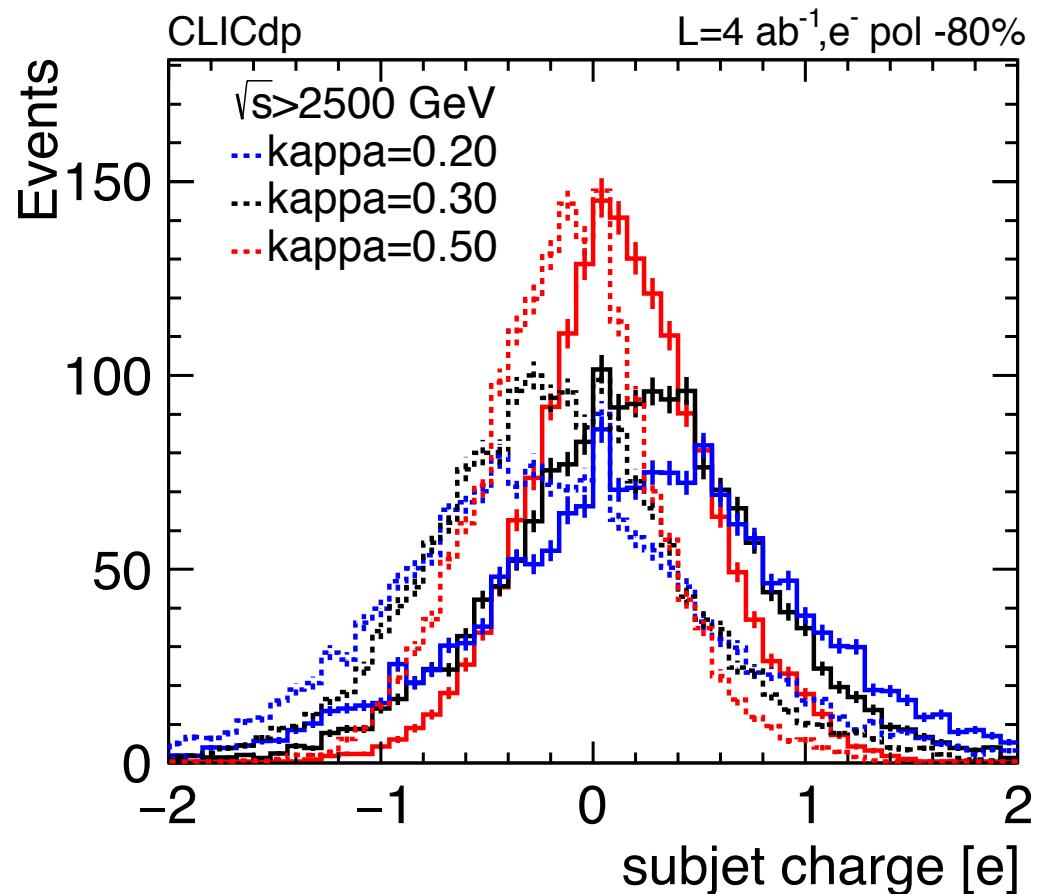
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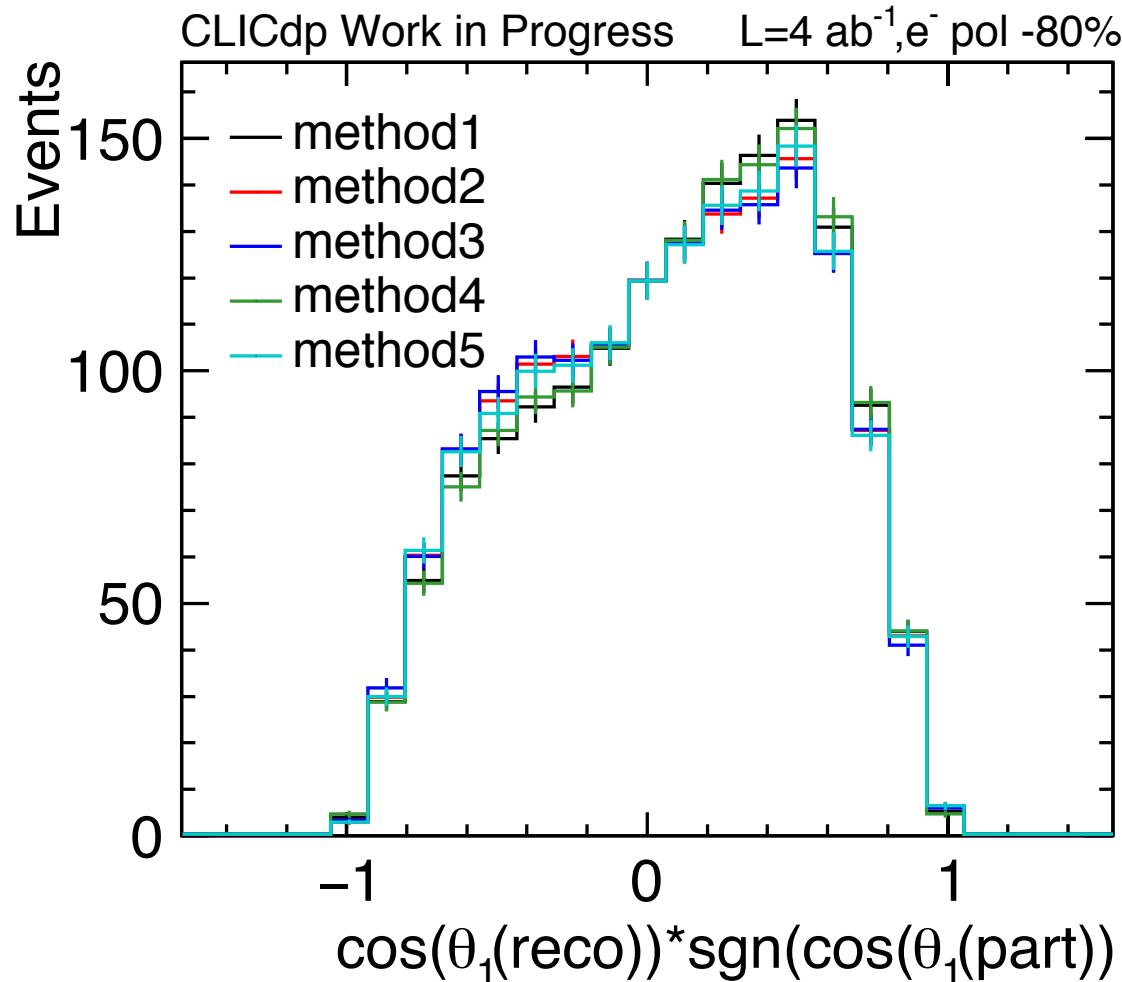
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Selection of positive charged quark



Selection based on largest absolute subjet charge works best,

Selection based on the subjet with the largest charged energy fraction works 2nd best



Background Rejection

Event Selection and Final Numbers



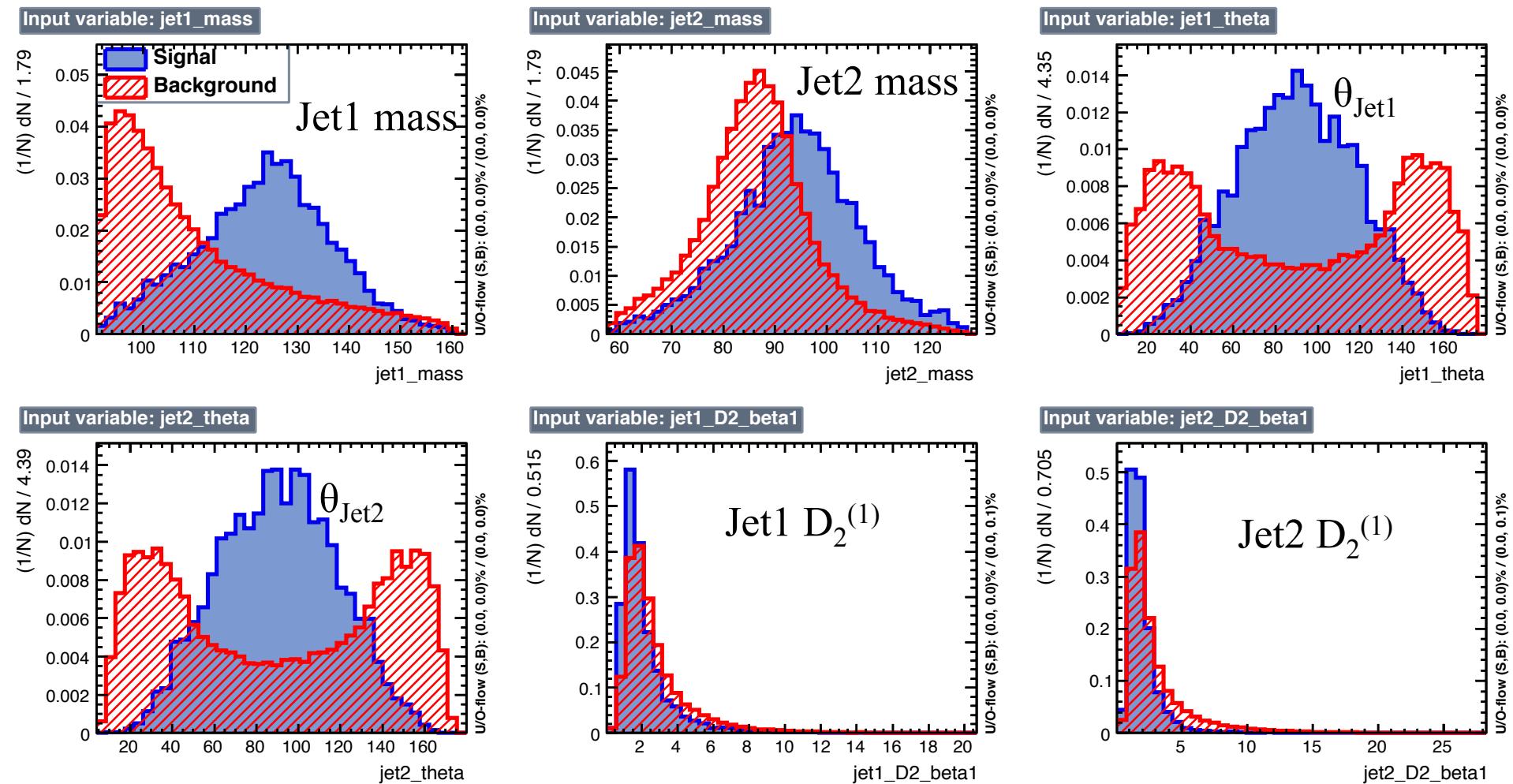
A 2-dimensional pre-selection is applied on the jet-masses, keeping about 85-89 % of signal, while rejecting up to 95 % of background events

process	Events neg pol	Evts after cut neg pol	Efficiency neg pol, in [%]	Events pos pol	Evts after cut pos pol	Efficiency pos pol [in%]
$ee \rightarrow HZ, H \rightarrow b\bar{b}$	1740	1541	89	304	268	88
$ee \rightarrow HZ, \text{all } H$	2600	2210	85	458	388	85
$ee \rightarrow q\bar{q}$	172 000	25 019	15	18 600	2680	14
$ee \rightarrow q\bar{q}q\bar{q}$	248 000	91 100	37	8 450	3190	38
$ee \rightarrow q\bar{q}q\bar{q}q\bar{q}$	32 200	3190	9.9	3 090	145	4.7

The final selection keeps about 33 (40)% of all events, 45 (55)% of $H \rightarrow b\bar{b}$ decays for negative (positive) electron beam polarisation

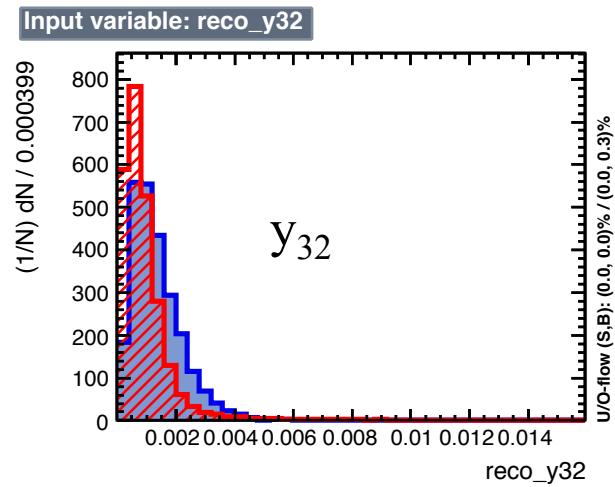
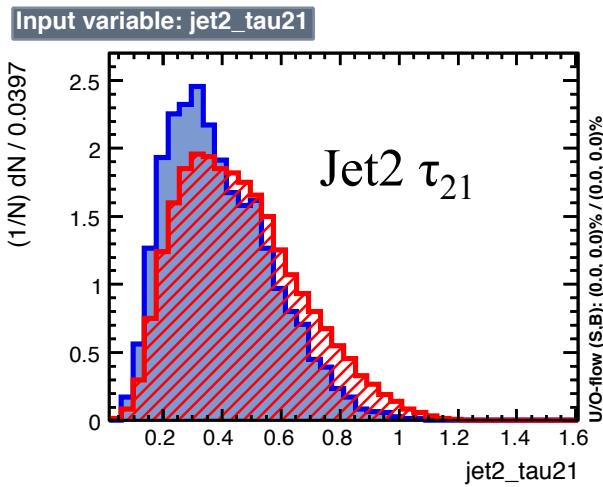
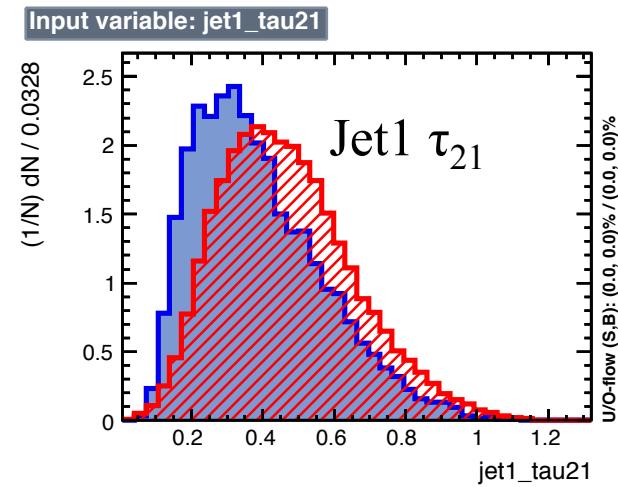
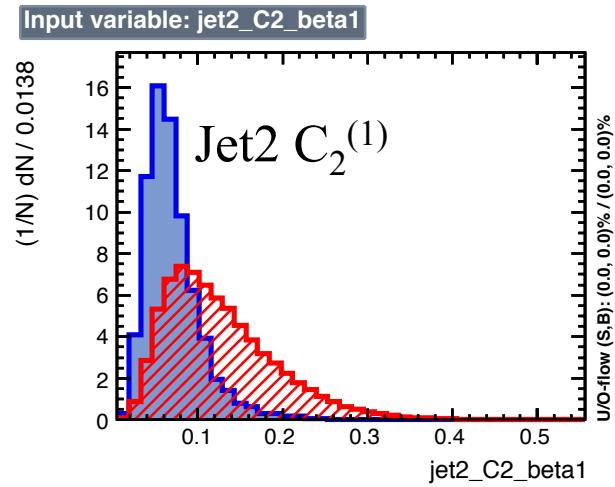
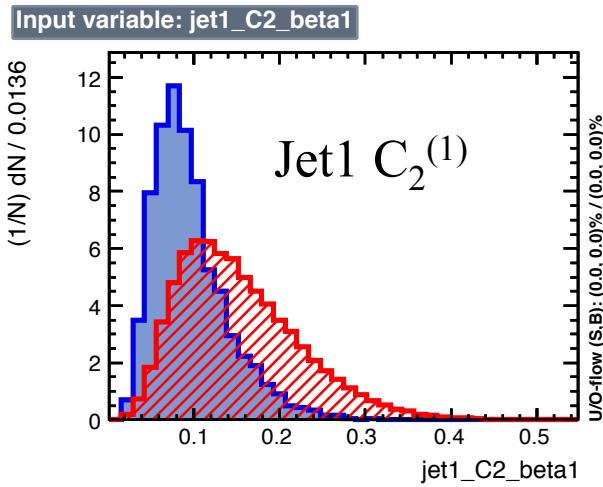
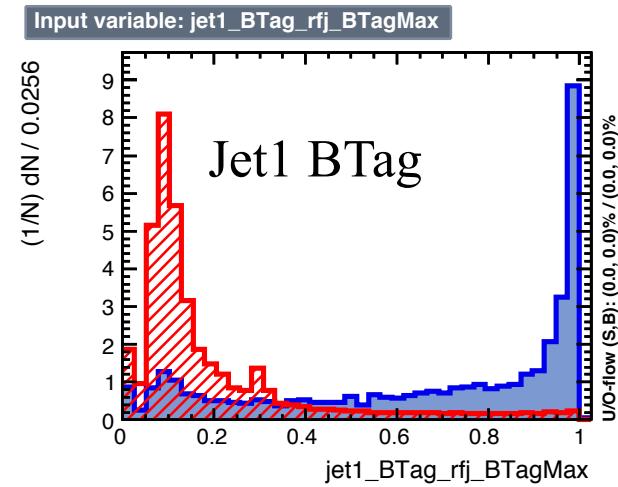
process	Events neg pol	Purity neg pol, in [%]	Efficiency neg pol, in [%]	Events pos pol	Purity pos pol [in%]	Efficiency pos pol [in%]
$ee \rightarrow HZ, H \rightarrow b\bar{b}$	789	52	45	167	61	55
$ee \rightarrow HZ, \text{all } H$	853	56	33	185	68	40
$ee \rightarrow q\bar{q}$	256	17	0.15	39.6	15	0.081
$ee \rightarrow q\bar{q}q\bar{q}$	333	22	0.12	40.7	15	0.18
$ee \rightarrow q\bar{q}q\bar{q}q\bar{q}$	74.4	4.9	0.23	7.37	2.7	0.24

Input Variables(1): negative polarisation



Input Variables in boosted decision tree, same input for positive and negative polarisation datasets: jet masses, polar angles, jet resolution threshold y_{23}

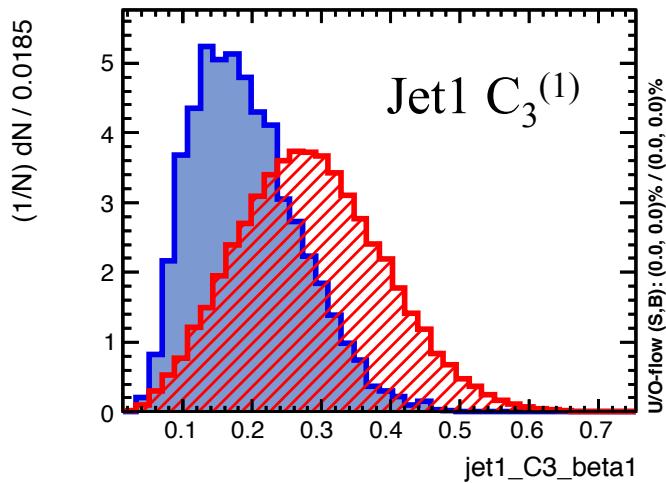
Input Variables(2): negative polarisation



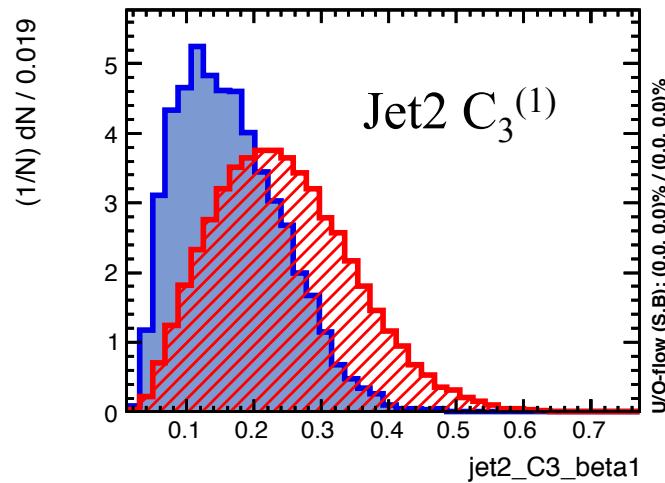
Input Variables in boosted decision tree: substructure variables for both jets τ_{21} , $C_2^{(1)}$, $C_3^{(1)}$, $D_2^{(1)}$

Input Variables(3): negative polarisation

Input variable: jet1_C3_beta1



Input variable: jet2_C3_beta1



$$\text{ECF}(N, \beta) = \sum_{i_1 < i_2 < \dots < i_N \in J} \left(\prod_{a=1}^N p_{T,i_a} \right) \left(\prod_{b=1}^{N-1} \prod_{c=b+1}^N R_{i_b i_c} \right)^\beta \quad C_N^{(\beta)} \equiv \frac{r_N^{(\beta)}}{r_{N-1}^{(\beta)}} = \frac{\text{ECF}(N+1, \beta) \text{ECF}(N-1, \beta)}{\text{ECF}(N, \beta)^2}$$

$$\text{ECF}(1, \beta) = \sum_{i \in J} p_{T,i},$$

$$\text{ECF}(2, \beta) = \sum_{i < j \in J} p_{T,i} p_{T,j} (R_{ij})^\beta,$$

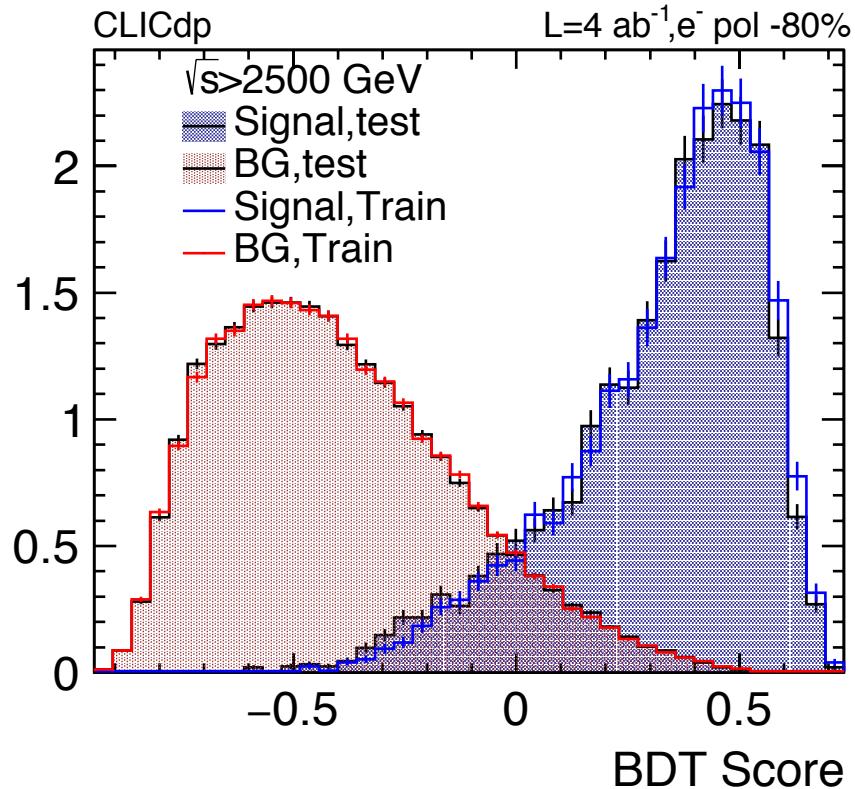
$$\text{ECF}(3, \beta) = \sum_{i < j < k \in J} p_{T,i} p_{T,j} p_{T,k} (R_{ij} R_{ik} R_{jk})^\beta,$$

Input Variables in boosted decision tree: substructure variables for both jets τ_{21} , $C_2^{(1)}$, $C_3^{(1)}$, $D_2^{(1)}$

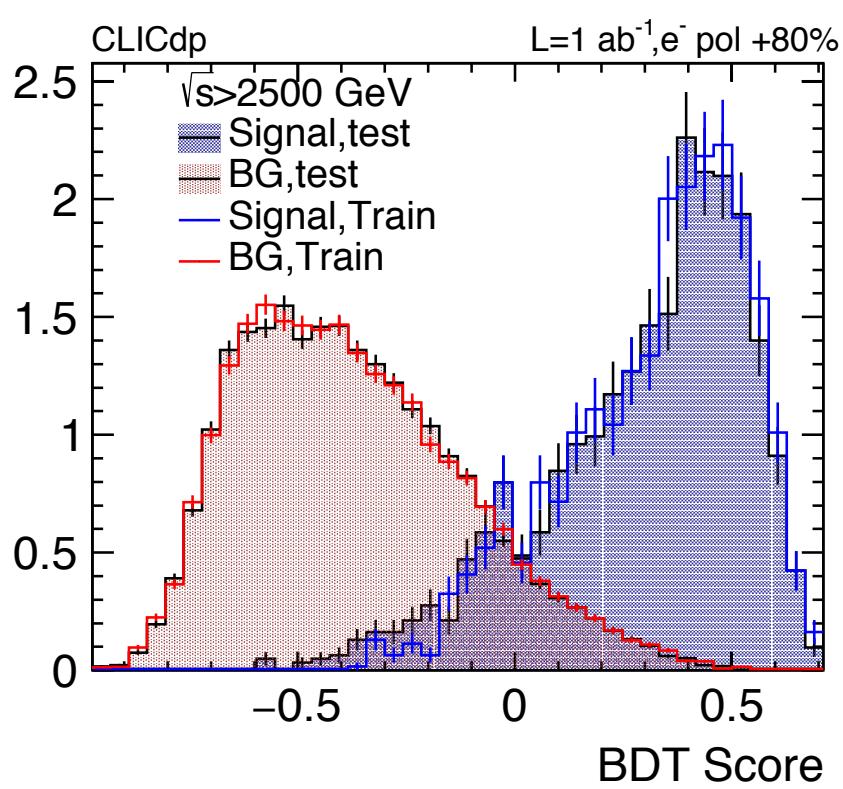
BDT-Score for Test and Training



Entries



Entries

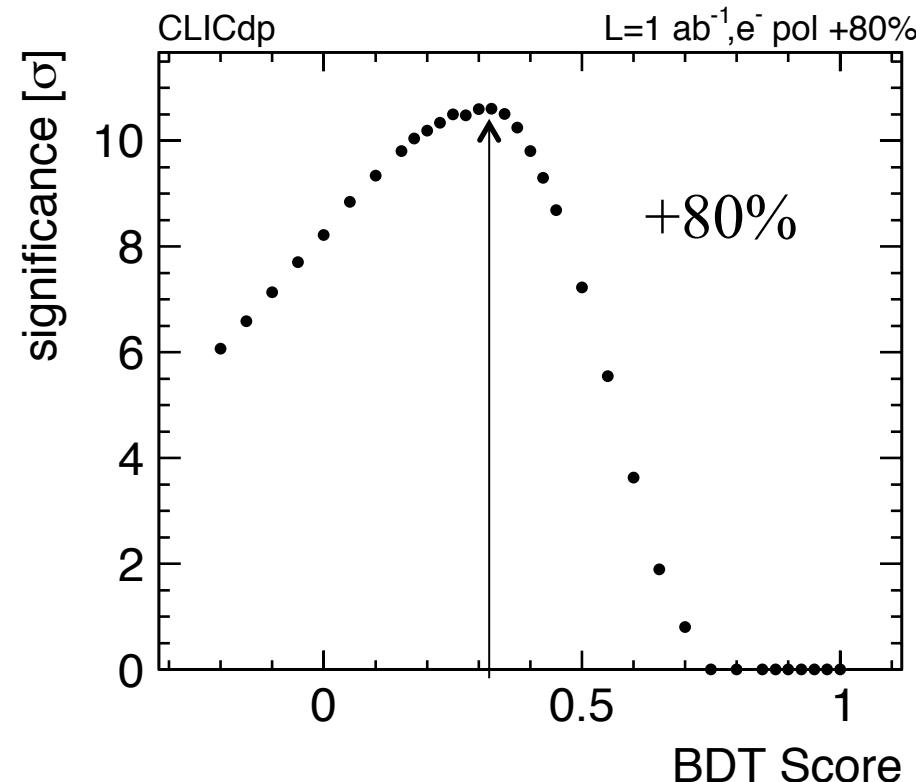
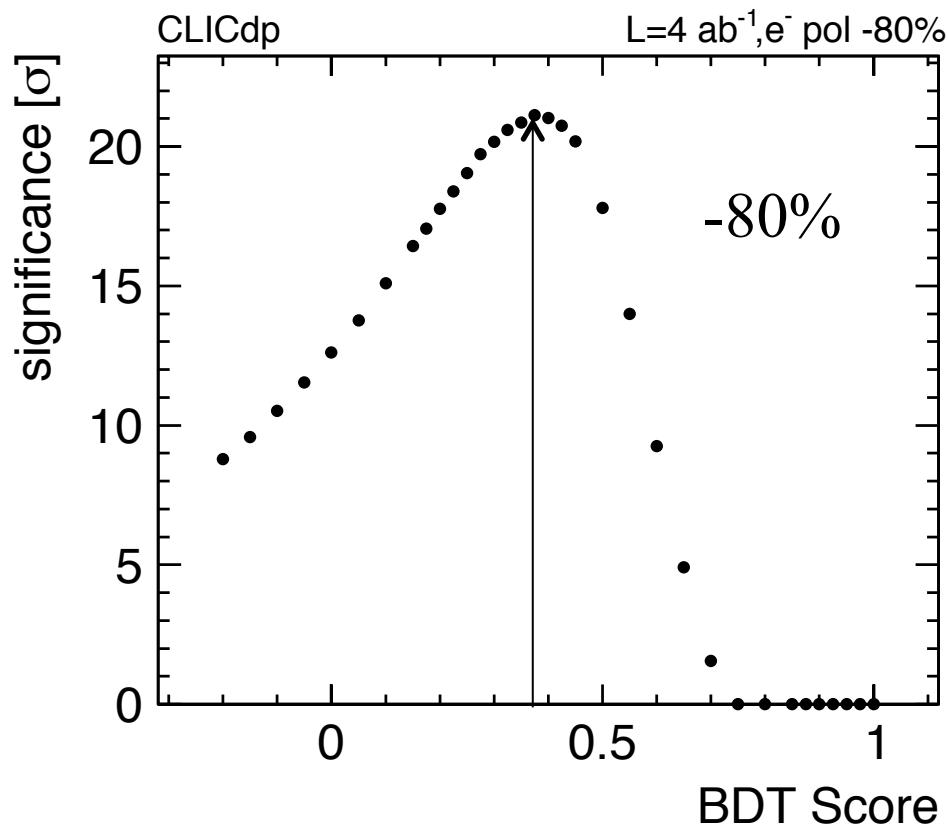


Check BDT score distribution for training and testing event
→ good agreement between distributions
→ no sign of worrisome overtraining

BDT cut for positive and negative polarisation



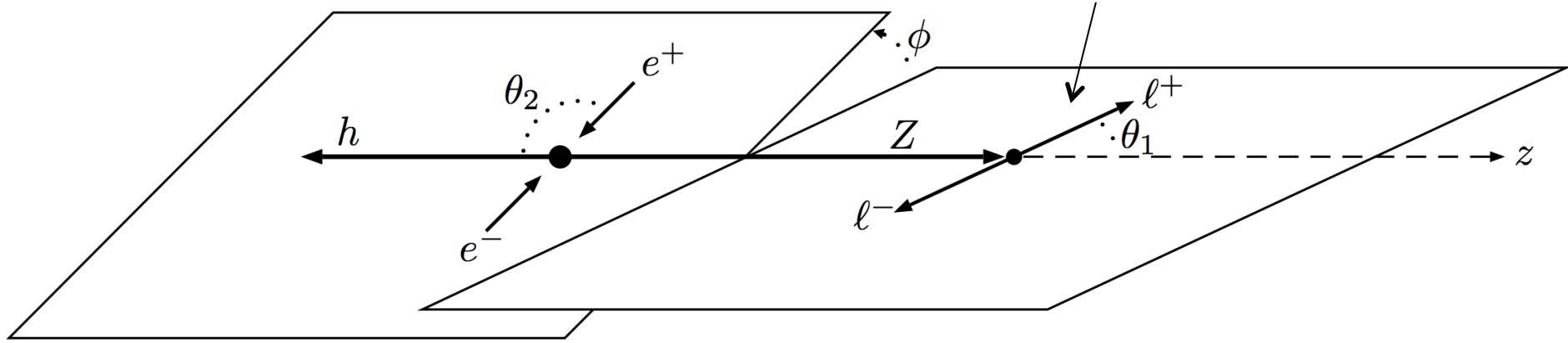
Significance of 21.9 (11.2) for BDT score > 0.40 (0.325) for e^- pol of -80% (+80%), S: signal defined as HZ with $Z \rightarrow qq$



Angular Distributions

Definition of Angles

Replace by q^+



θ_2 angle between H and e^+ in e^+e^- restframe (leading jet and e^+)

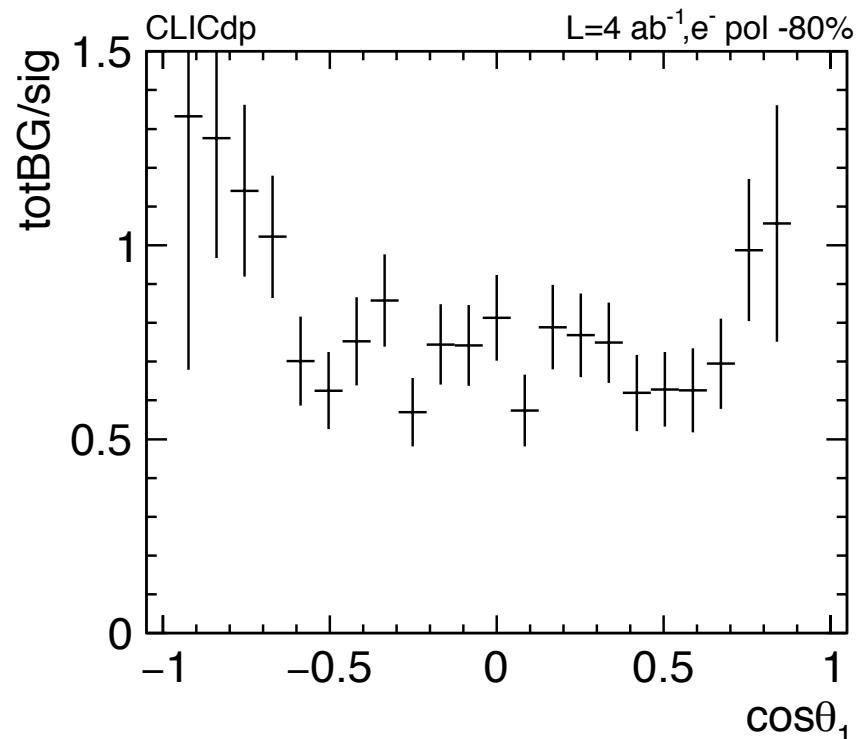
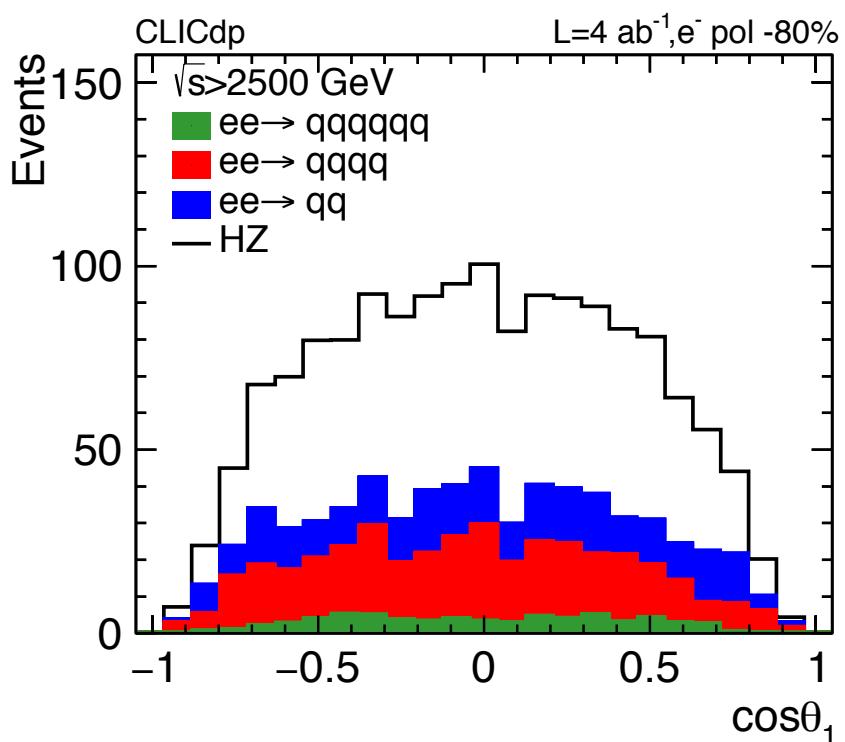
θ_1 angle between Z and positive charged quark and original Z direction (in e^+e^-) in Z restframe (second leading jet, subjet with assigned positive quark)

Φ angle between the two planes

Definition: Angular Variables

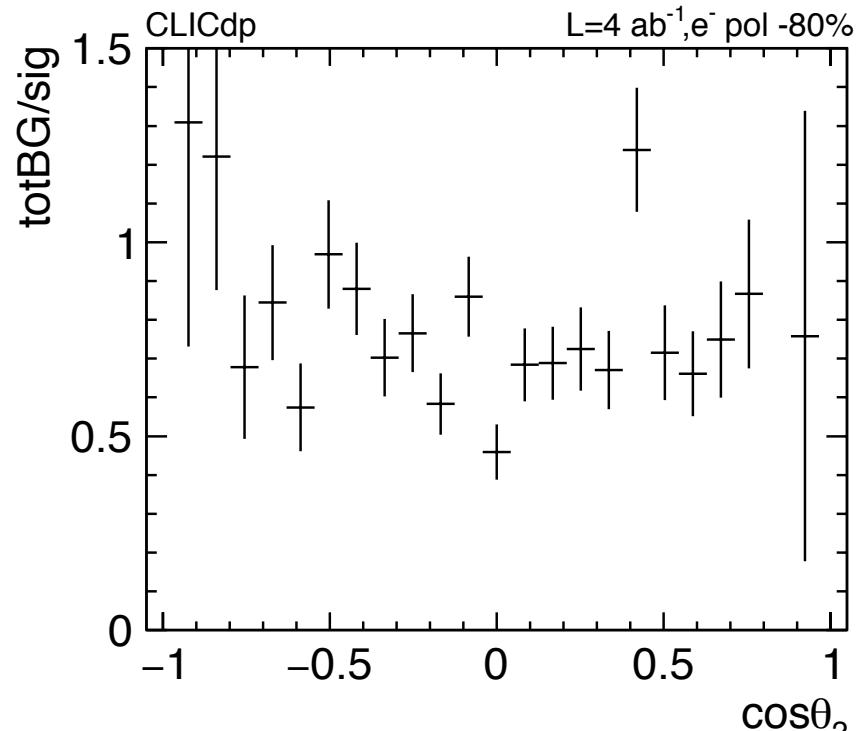
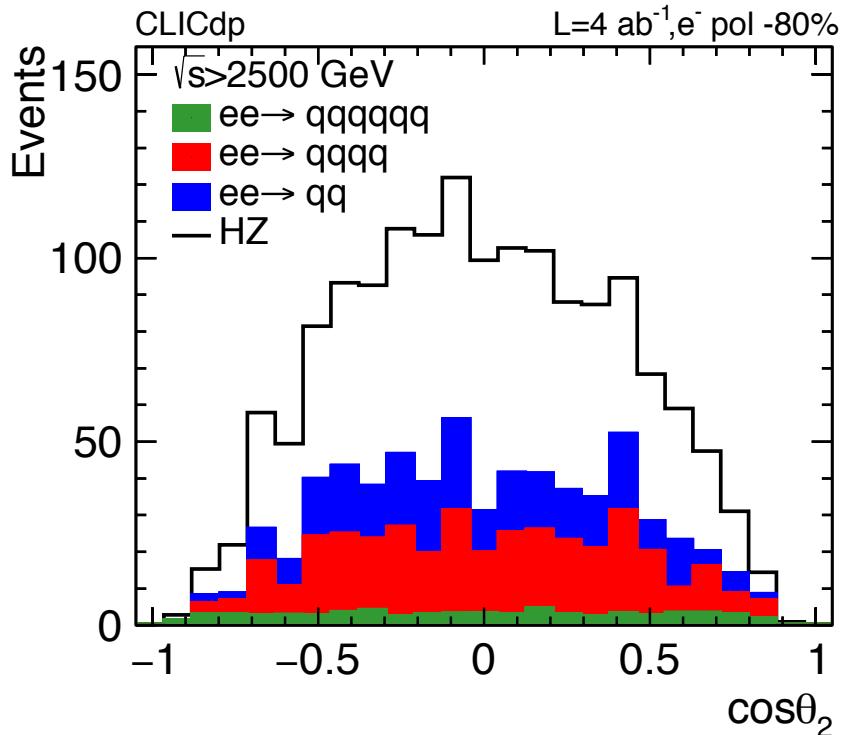
$$\begin{aligned}
\mathcal{A}_{\theta_1} &= \frac{1}{\sigma} \int_{-1}^1 d \cos \theta_1 \operatorname{sgn}(\cos(2\theta_1)) \frac{d\sigma}{d \cos \theta_1} \\
&= 1 - \frac{5}{2\sqrt{2}} + \frac{3J_1}{\sqrt{2}(4J_1 + J_2)} \\
\mathcal{A}_\phi^{(1)} &= \frac{1}{\sigma} \int_0^{2\pi} d\phi \operatorname{sgn}(\sin \phi) \frac{d\sigma}{d\phi} = \frac{9\pi}{32} \frac{J_4}{4J_1 + J_2} \\
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\mathcal{A}_\phi^{(3)} &= \frac{1}{\sigma} \int_0^{2\pi} d\phi \operatorname{sgn}(\cos \phi) \frac{d\sigma}{d\phi} = \frac{9\pi}{32} \frac{J_6}{4J_1 + J_2} \\
\mathcal{A}_\phi^{(4)} &= \frac{1}{\sigma} \int_0^{2\pi} d\phi \operatorname{sgn}(\cos(2\phi)) \frac{d\sigma}{d\phi} = \frac{2}{\pi} \frac{J_9}{4J_1 + J_2} \\
\mathcal{A}_{c\theta_1, c\theta_2} &= \frac{1}{\sigma} \int_{-1}^1 d \cos \theta_1 \operatorname{sgn}(\cos \theta_1) \int_{-1}^1 d \cos \theta_2 \operatorname{sgn}(\cos \theta_2) \frac{d^2\sigma}{d \cos \theta_1 d \cos \theta_2} \\
&= \frac{9}{16} \frac{J_3}{4J_1 + J_2}.
\end{aligned}$$

$\cos \theta_1$ distribution



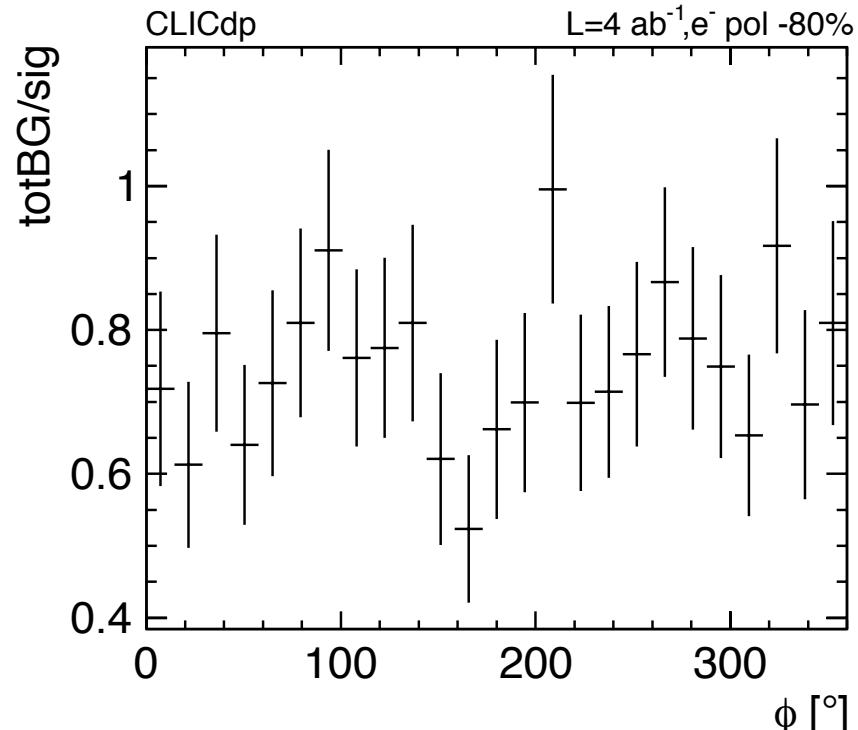
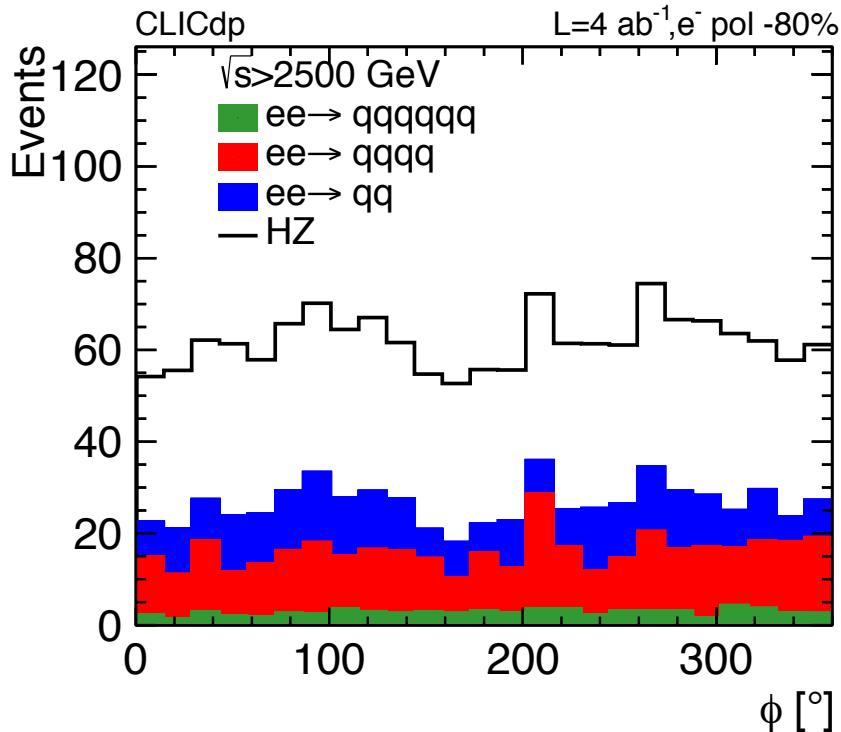
Background distribution not far different from signal distribution for most values (similar for +80% case)

$\cos \theta_2$ distribution



Here use total event energy and p_Z to determine e^+ direction, ignore crossing angle offset in p_X , less variation between signal and background shape

Phi distribution



Rather flat distribution, also background contribution rather flat as well \rightarrow consider orientation of positive quark with respect to normal vector of H-e⁺ plane

Angular Variables:

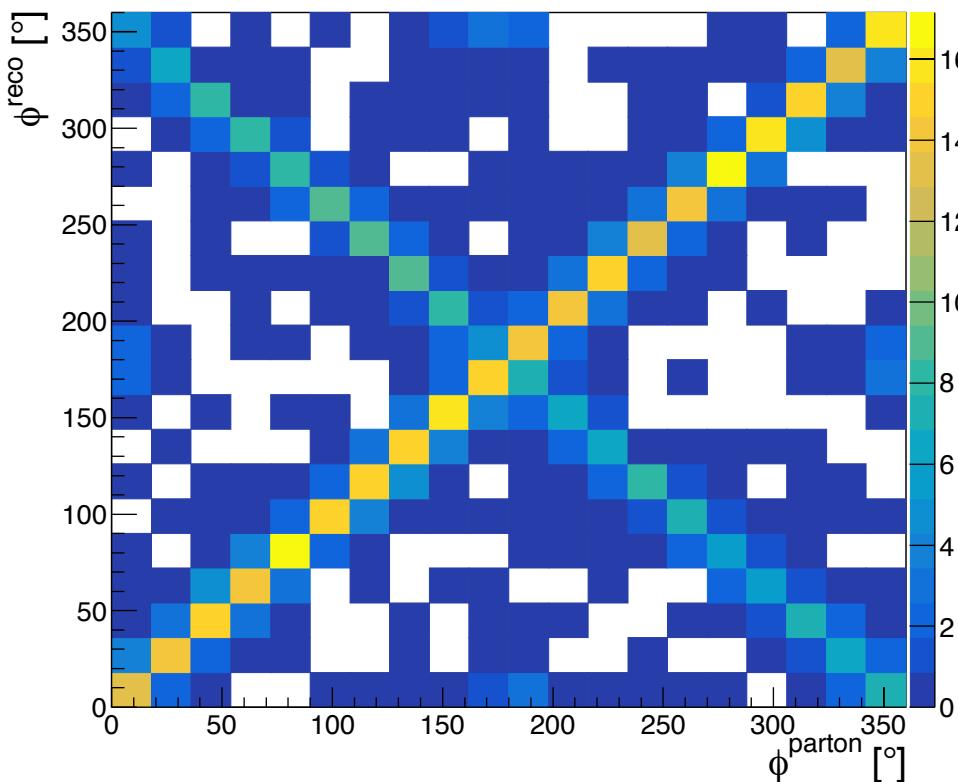
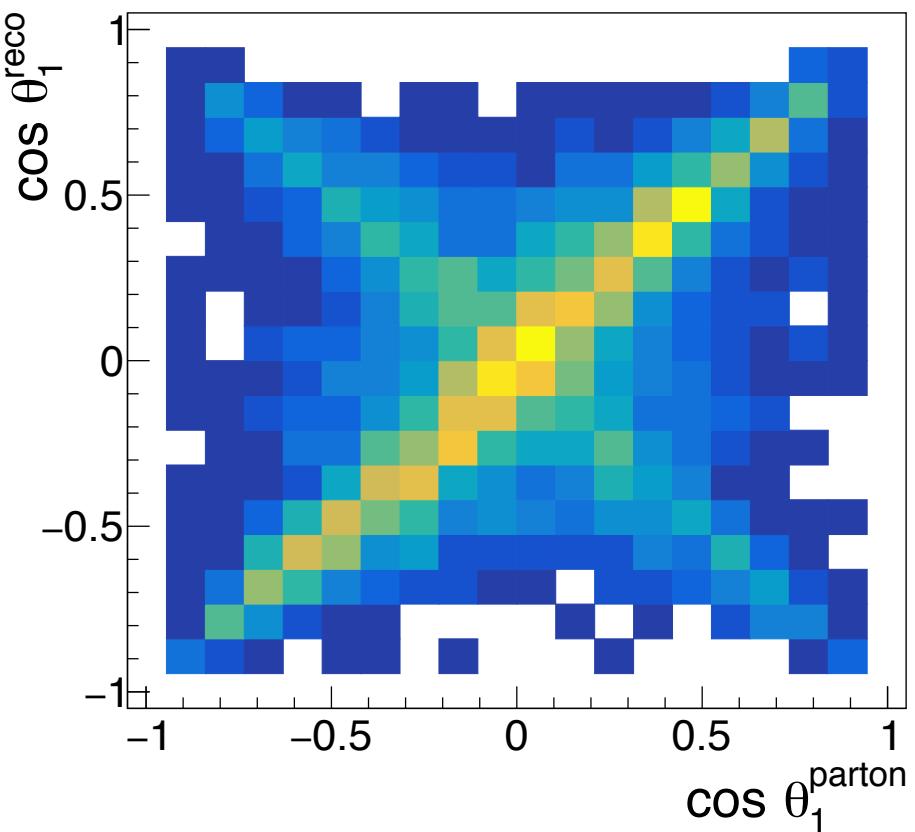
Negative polarisation

Asymmetry	ee → HZ H → b <bar>b</bar>	ee → HZ all H	Backgrounds	ee → HZ and BKG	Parton Level
$A_{c\theta_1,c\theta_2}$	0.019±0.035	0.021±0.034	0.028±0.039	0.024±0.025	-0.021±0.019
A_{θ_1}	-0.834±0.019	-0.837±0.018	-0.760±0.025	-0.80±0.015	-0.765±0.012
$A_{\phi}^{(1)}$	-0.002±0.035	-0.004±0.034	-0.050±0.039	-0.024±0.026	-0.005±0.019
$A_{\phi}^{(2)}$	-0.014±0.035	-0.011±0.034	-0.000±0.039	-0.006±0.026	-0.037±0.019
$A_{\phi}^{(3)}$	-0.001±0.035	-0.004±0.034	0.007±0.039	0.001±0.026	0.003±0.019
$A_{\phi}^{(4)}$	-0.036±0.035	-0.037±0.034	-0.07±0.039	-0.049±0.026	-0.015±0.019

Positive polarisation

Asymmetry	ee → HZ H → b <bar>b</bar>	ee → HZ all H	Backgrounds	ee → HZ and BKG	Parton Level
$A_{c\theta_1,c\theta_2}$	-0.006±0.077	-0.014±0.073	-0.035±0.107	-0.021±0.061	0.000±0.046
A_{θ_1}	-0.818±0.044	-0.827±0.041	-0.689±0.077	-0.783±0.038	-0.761±0.030
$A_{\phi}^{(1)}$	0.014±0.077	0.007±0.073	-0.067±0.107	-0.016±0.061	0.021±0.046
$A_{\phi}^{(2)}$	0.009±0.077	0.005±0.073	-0.033±0.107	-0.007±0.061	0.051±0.046
$A_{\phi}^{(3)}$	0.061±0.077	0.059±0.073	-0.009±0.107	0.038±0.060	0.041±0.046
$A_{\phi}^{(4)}$	-0.052±0.077	-0.040±0.073	-0.056±0.107	-0.046±0.060	0.004±0.046

Unfolding Matrix example: $\cos \theta_1$ and Φ



Diagonal and anti-diagonal elements dominate → wrong subject chosen, opposite in θ_1 , analogous impact on angle Φ
 → event remains in the same hemisphere for most asymmetry observables

Summary

Investigate several methods to determine positive quark

- Method using the absolute subjet charge works best

Propagate MET projection correction for \sqrt{s} and jet mass calculation

→ Improves agreement between reconstructed and parton quantities

Detailed studies on choice of BDT selection

First look at angular asymmetries, behavior for $A_{\theta 1}$ distribution different from the other distributions

- $A_{\theta 1}$ after cuts shifted to slightly larger values, CLIC theory value around -0.76
→ depends on selection on substructure of second jet
→ removing substructure of second jet from BDT increases background contribution,
- Expectation for other variables equal or very close to 0

Outlook: Note in preparation

First version almost ready to be circulated



CLICdp-Draft-2019-xxx
26 August 2019

1

Draft note at: https://gitlab.cern.ch/CLICdp/Publications/DraftDocuments/note_hadronichzat3tev

2

All-hadronic HZ production at high energy at 3 TeV CLIC

3

M. Weber^{a,b}

4

On behalf of the CLICdp Collaboration

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^a CERN, Switzerland, ^b University of Glasgow, United Kingdom

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Abstract

7

In this note the all-hadronic HZ production in e^+e^- collisions at the Compact Linear Collider is studied at the largest energy-stage of 3 TeV. At high energies back-to-back the events have an experimental signature of back-to-back approximately mono-energetic large jets. Each of these jets contains two sub-jets and substructure compatible with two original objects. The study is based on fully simulated events including the presence of beam-induced background from $\gamma\gamma \rightarrow$ hadrons.

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BACKUP

MC Datasets: Whizard2 production



Table 1: Signal and background datasets with $y = d, s, b$, $L = 4 \text{ ab}^{-1}$ for $P(e^-)=-80\%$, $L = 1 \text{ ab}^{-1}$ for $P(e^-)=+80\%$:

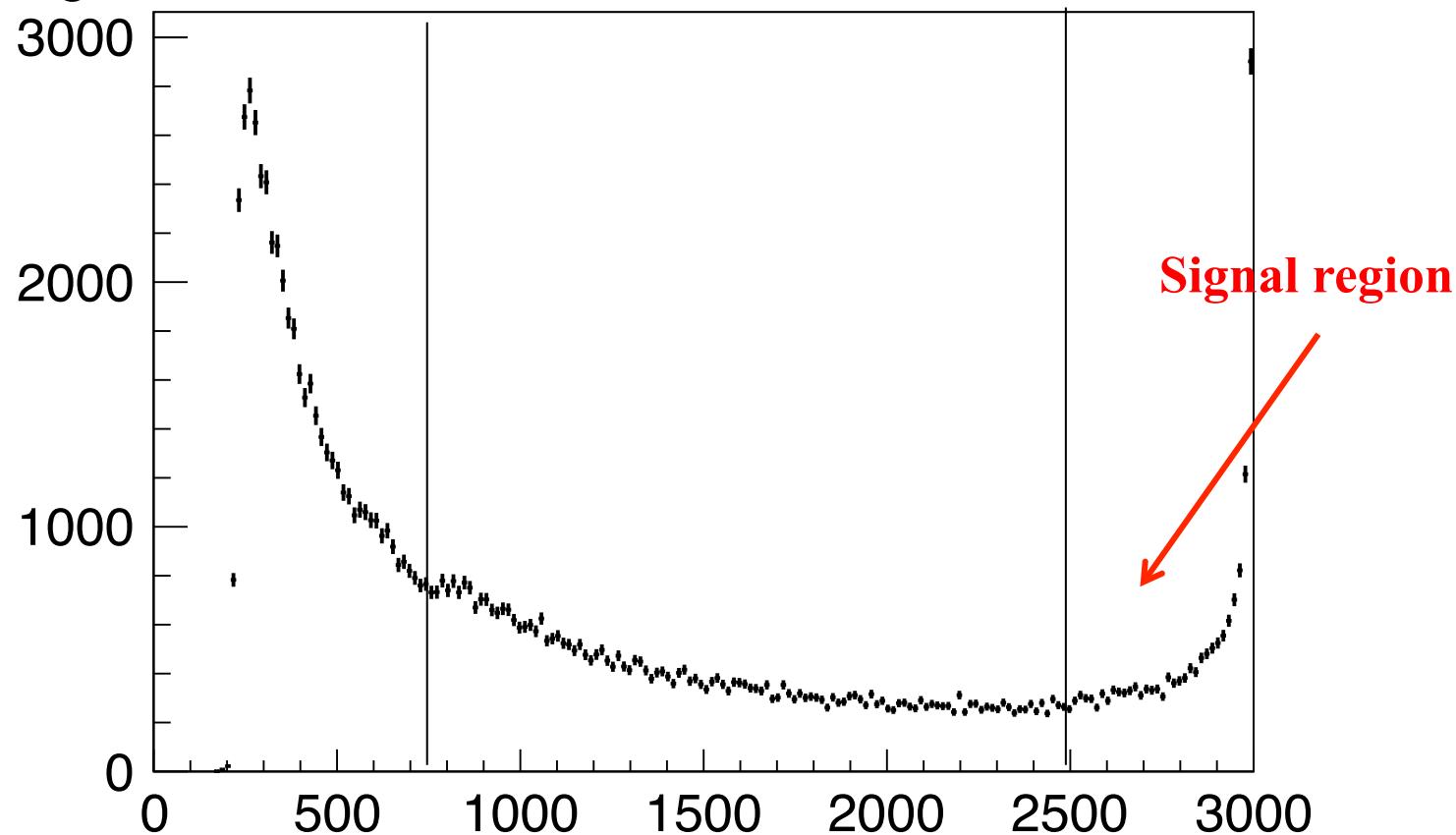
process	additional cuts	Events	$\sigma[\text{fb}]$	Polarisation	event weight
$ee \rightarrow HZ$	-	114000	3.83	$P(e^-)=-80\%$	0.134
$ee \rightarrow HZ$	-	27840	2.76	$P(e^-)=+80\%$	0.0959
$ee \rightarrow HZ$	-	27840	2.76	$P(e^-)=+80\%$	0.0959
$ee \rightarrow q\bar{q}$	-	1549464	1269	$P(e^-)=-80\%$	3.28
$ee \rightarrow q\bar{q}$	-	388392	786	$P(e^-)=+80\%$	2.02
$ee \rightarrow q\bar{q}$	$m_{q\bar{q}} > 1 \text{ TeV}$	1519910	170.8	$P(e^-)=-80\%$	0.445
$ee \rightarrow q\bar{q}$	$m_{q\bar{q}} > 1 \text{ TeV}$	382464	73.5	$P(e^-)=+80\%$	0.192
$ee \rightarrow q\bar{q}q\bar{q}$	-	1915464	902	$P(e^-)=-80\%$	1.88
$ee \rightarrow q\bar{q}q\bar{q}$	-	479040	120	$P(e^-)=+80\%$	0.251
$ee \rightarrow q\bar{q}q\bar{q}$	$m_{q\bar{q}q\bar{q}} > 2 \text{ TeV}$	1522935	369.8	$P(e^-)=-80\%$	0.971
$ee \rightarrow q\bar{q}q\bar{q}$	$m_{q\bar{q}q\bar{q}} > 2 \text{ TeV}$	380451	49.2	$P(e^-)=+80\%$	0.129
$ee \rightarrow dduyyu$	-	456336	14.5	$P(e^-)=-80\%$	0.127
$ee \rightarrow dduyyu$	-	121200	5.01	$P(e^-)=+80\%$	0.0413
$ee \rightarrow yyubb$ c	-	428405	13.3	$P(e^-)=-80\%$	0.124
$ee \rightarrow yyubb$ c	-	123720	5.21	$P(e^-)=+80\%$	0.0421
$ee \rightarrow sscbbc$	-	330096	12.5	$P(e^-)=-80\%$	0.151
$ee \rightarrow sscbbc$	-	84240	4.89	$P(e^-)=+80\%$	0.0581

Effective centre of mass energy for HZ

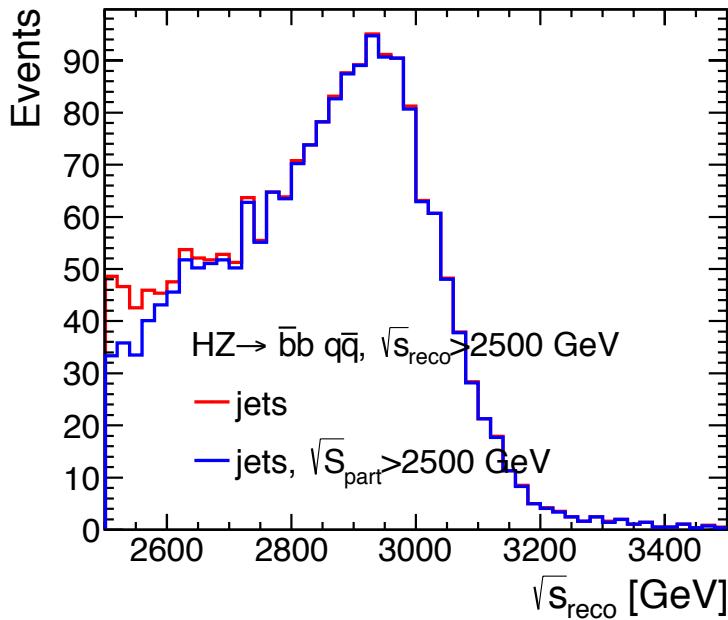
Effective Centre-of-mass energy of e⁺e⁻ after ISR photons and beam strahlung on parton level

→ cross-section falling with centre of mass energy + luminosity spectrum

→ define 3 regions <750, 750-2500,>2500 GeV



sqrt(s) purity

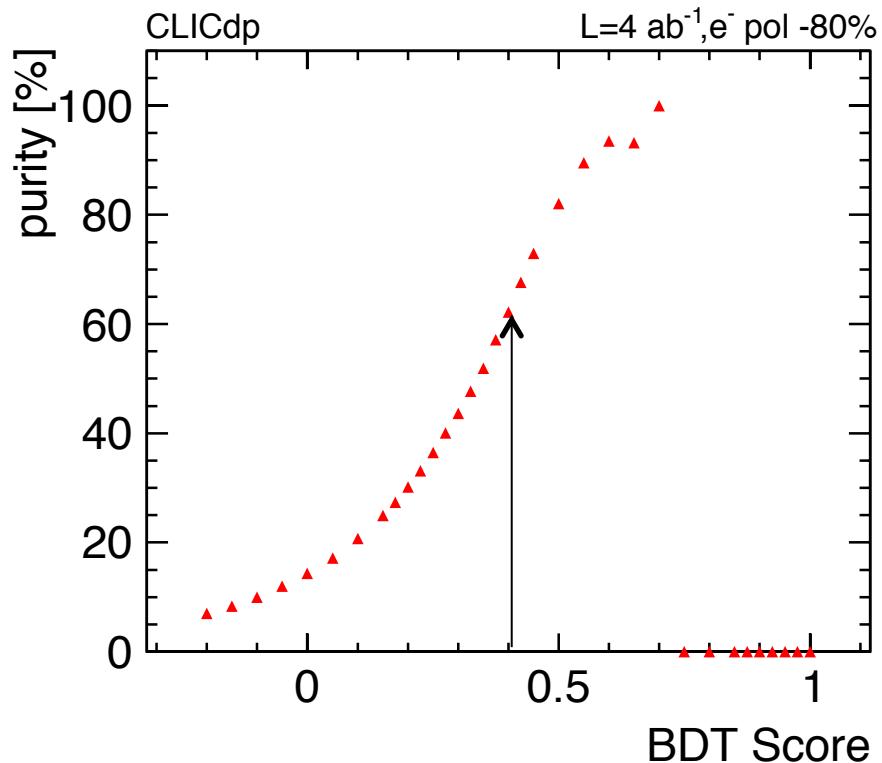
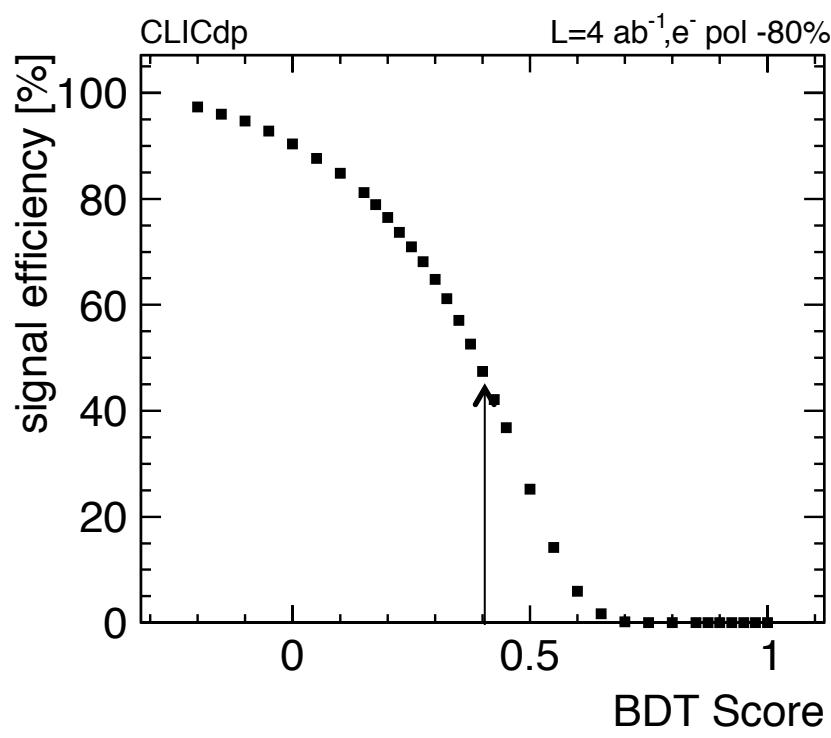


Calculation method	MC Evts $\sqrt{s}_{\text{reco}} > 2500$ GeV	MC Evts $\sqrt{s}_{\text{reco}} > 2500$ GeV and $\sqrt{s}_{\text{part}} > 2500$ GeV	purity
Tight PFOs	10387	9989	96.1
Tight PFOs+ MET correction	11982	11187	93.4
jets	9378	9252	98.7
jets+MET correction	11102	10759	96.9

BDT cut for negative polarisation

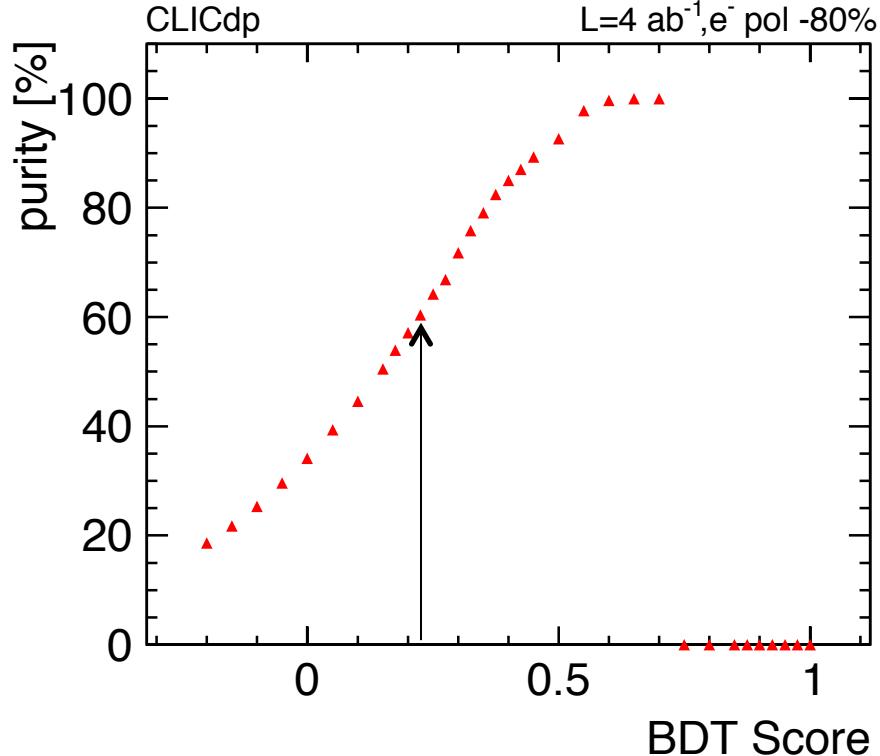
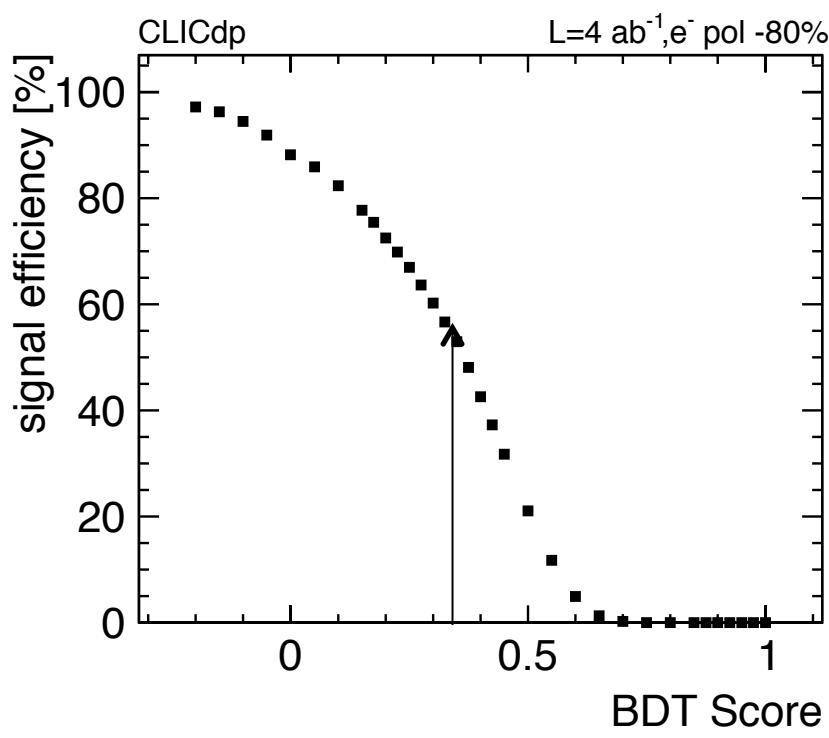


Significance of 21.9 for BDT score >0.40 for e^- pol of -80% for efficiency consider as $H \rightarrow bb$ $Z \rightarrow qq$ as signal



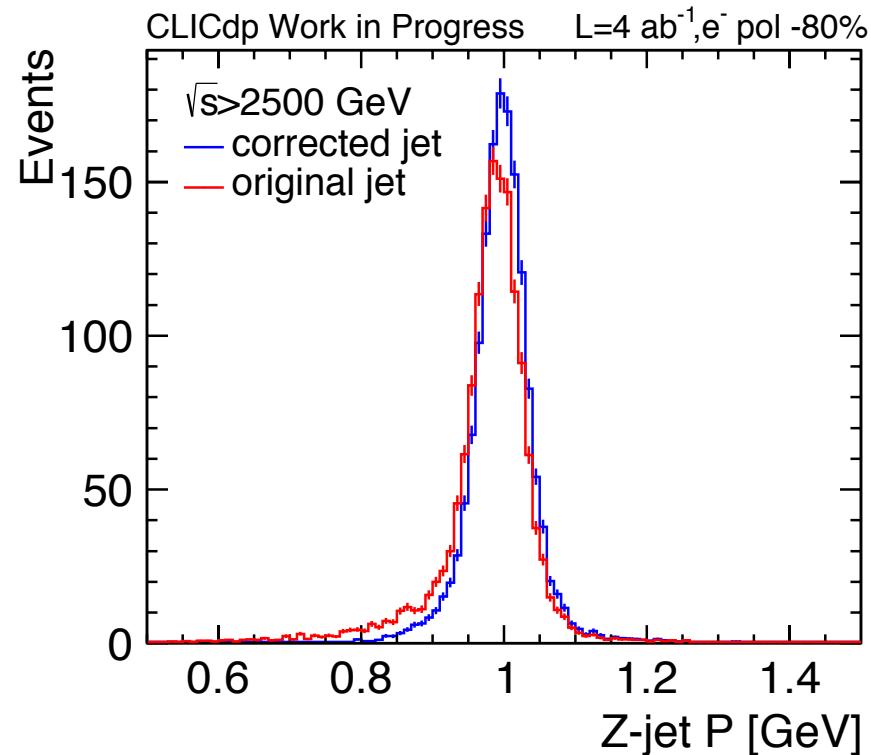
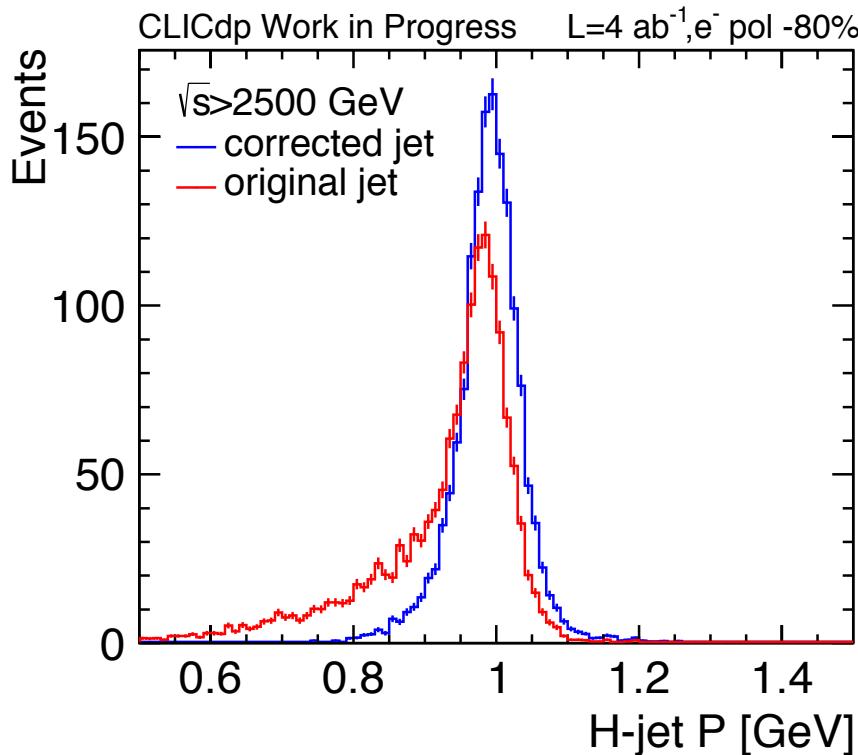
BDT cut for positive polarisation

Significance of 11.2 for BDT score >0.325 for e^- pol of +80% for efficiency consider as $H(\rightarrow bb)Z \rightarrow qq$ as signal



MET Projection and Jets

Project MET onto jets for improved jet mass and sqrtS calculation, so far not propagated into angular variables, improvement of jet momentum should improve angular variables



Total Cross-section: ee \rightarrow qqqqqq sum of 14 different six quark datasets

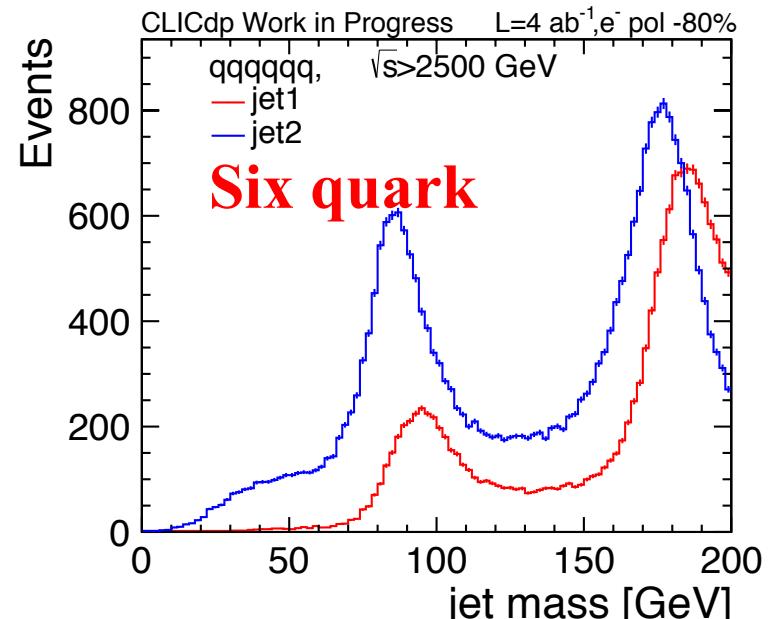
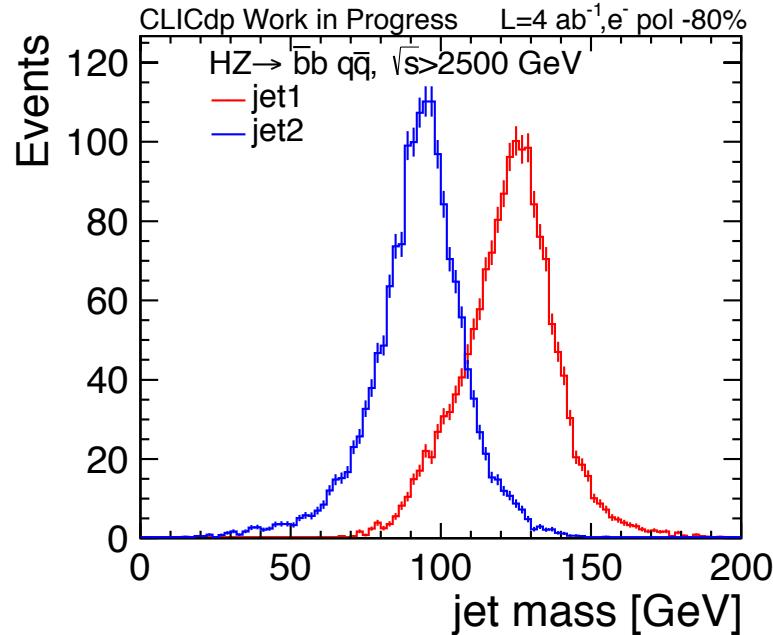
New samples for ee \rightarrow qq, cut on $m_{\text{qq}} > 1 \text{ TeV}$

ee \rightarrow qqqq, cut on $m_{\text{qqqq}} > 2 \text{ TeV}$

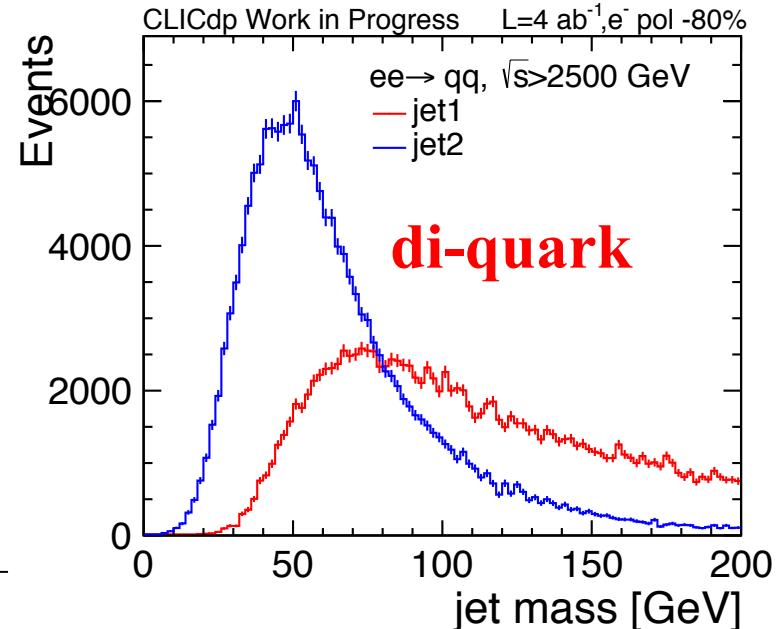
Process	Cross-section in fb Polarization e ⁻ -80 %	Cross-section in fb Polarization e ⁻ +80 %
HZ \rightarrow H qq	3.78	2.67
ee \rightarrow qq	1269/170.8 ($m_{\text{qq}} > 1 \text{ TeV}$)	786/73.5 ($m_{\text{qq}} > 1 \text{ TeV}$)
ee \rightarrow qqqq	902/396.8 ($m_{\text{qqqq}} > 2 \text{ TeV}$)	120/49.2 ($m_{\text{qqqq}} > 2 \text{ TeV}$)
ee \rightarrow qqqqqq	64.4	22.3

Leading jet masses

HZ signal



Six quark



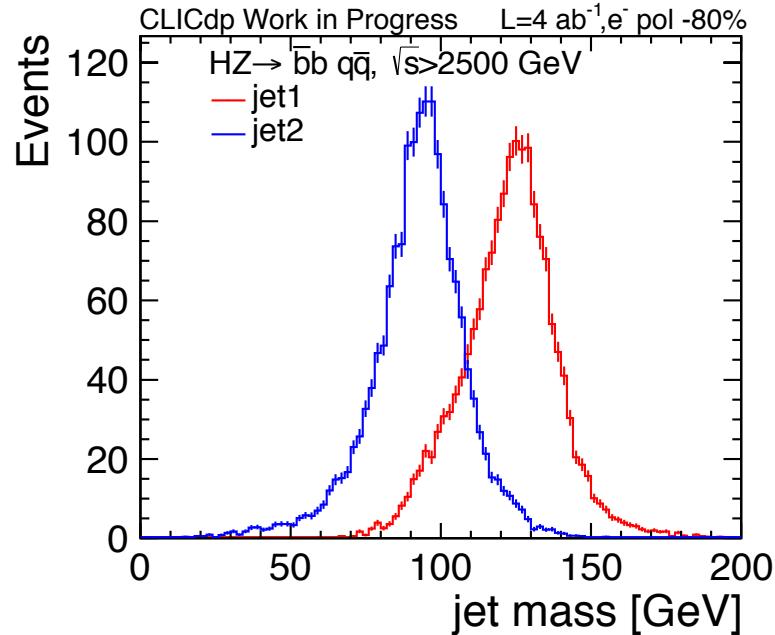
di-quark

Clear peak at Z and H mass for signal

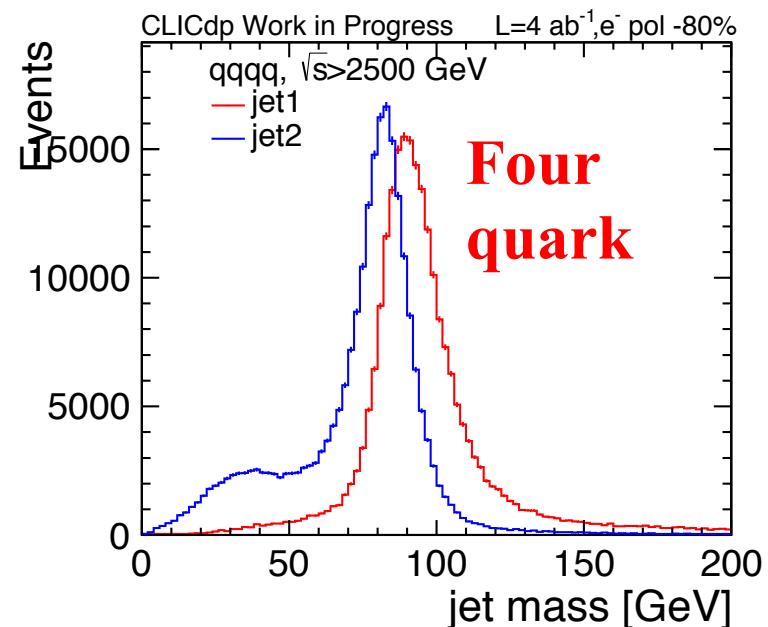
- for diquark sample peaks at lower values with long tail
- Six quark sample has leading peak around top mass, subleading peak around W mass

Cut on jet masses

HZ signal

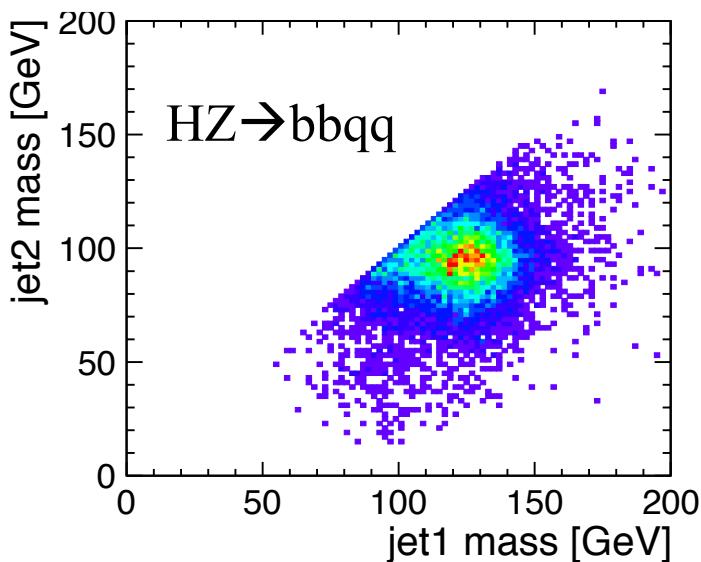
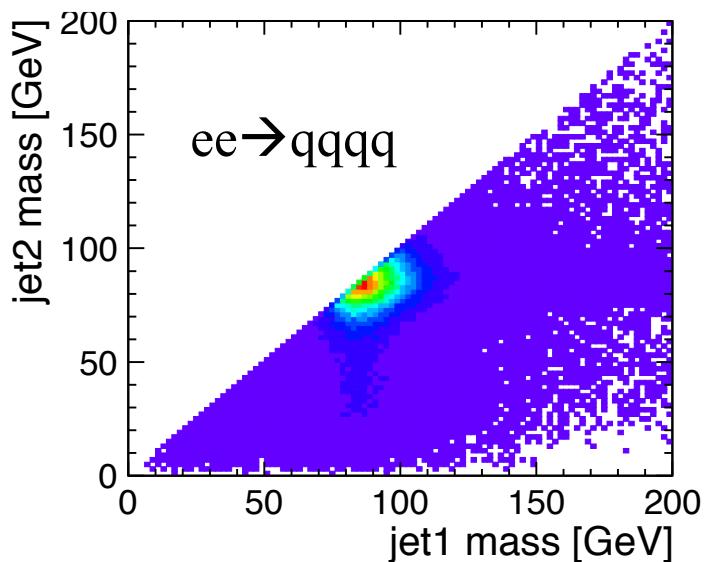
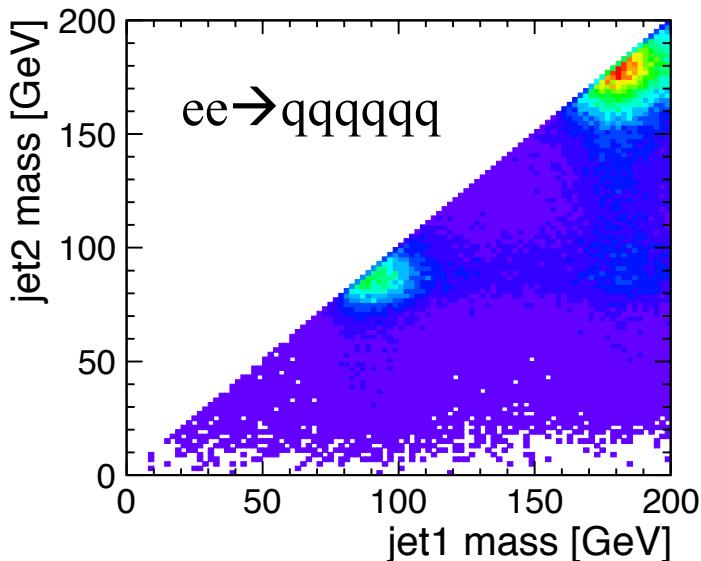
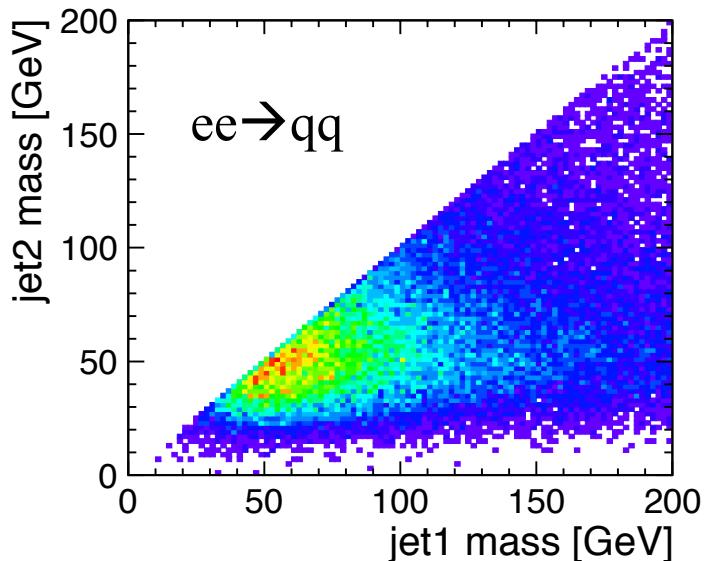


Apply two dimensional ellipse cut on jet1-jet2 mass plane around Z and H mass with windows of $\Delta m(j1) = \Delta m(j2) = 35$ GeV



Four quark sample has narrow peaks around W and Z masses
 \rightarrow sizeable tails to higher masses

Background and signal: jet 1 mass vs jet2 mass



BDT parameter tuning

Start with events preselected on jet masses m_{jet1} around 126 ± 35 , m_{jet2} around 92.5 ± 35 . Use Boosted Decision Tree as implemented in TMVA package interface of root.

→ Input variables: jet masses m_{j1} and m_{j2} , polar angles θ_{j1} and θ_{j2} , leading subjet btag value of leading jet $Btag_{max}(j1)$, substructure variables for leading jets with beta=1
 $C_2^{(1)}(j1), C_2^{(1)}(j2), C_3^{(1)}(j1), C_3^{(1)}(j2), D_2^{(1)}(j1), D_2^{(1)}(j2), \tau_{21}(j1), \tau_{21}(j2)$

→ Varied parameters for MaxDepth, SeparationType, NormMode, AdaBoostBeta and nCuts (use AdaBoost as BoostType)

→ Values chosen:

MaxDepth=3, SeparationType=GiniIndex, NormMode=NumEvents, AdaBoostBeta=0.20 and nCuts=-1

→ Varied parameters for MaxDepth, SeparationType, NormMode, Shrinkage and nCuts (use Grad as BoostType)

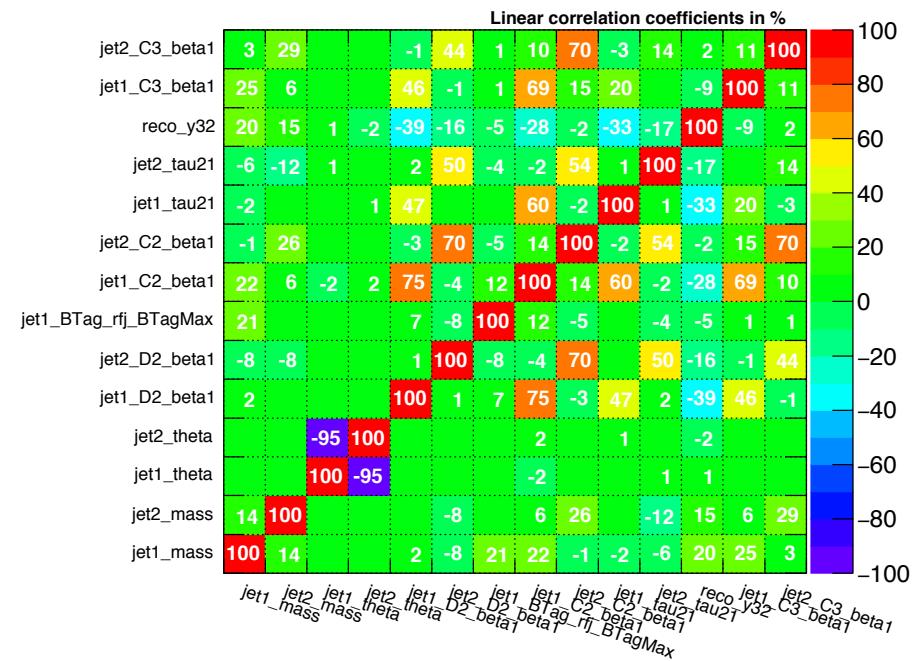
→ Values chosen:

MaxDepth=3, SeparationType=GiniIndex, NormMode=NumEvents, Shrinkage =1.00 and nCuts=20

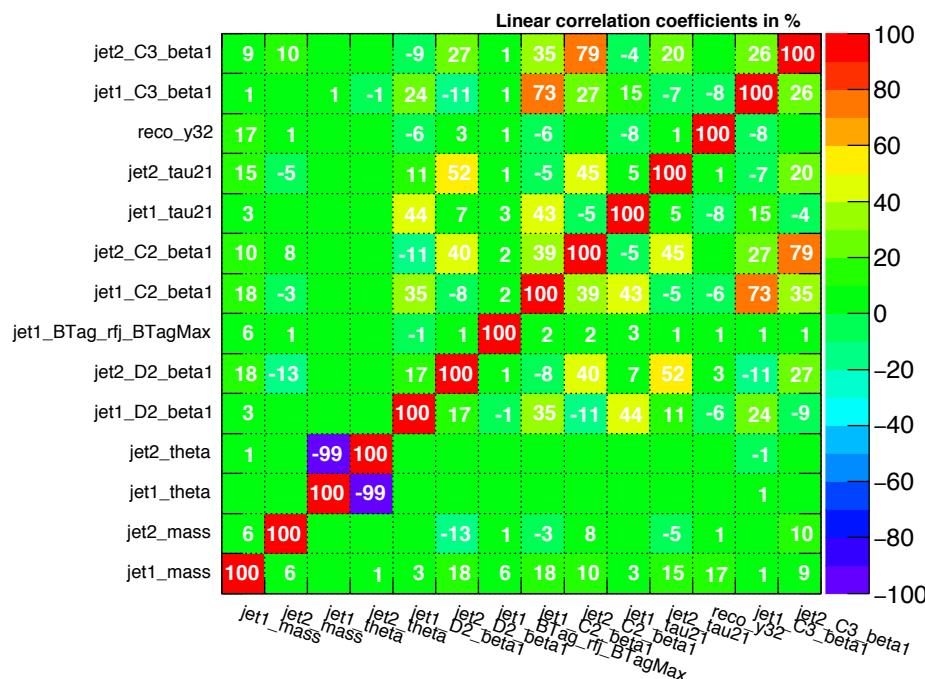
BDT: correlations between input variables: neg pol



Correlation Matrix (signal)



Correlation Matrix (background)

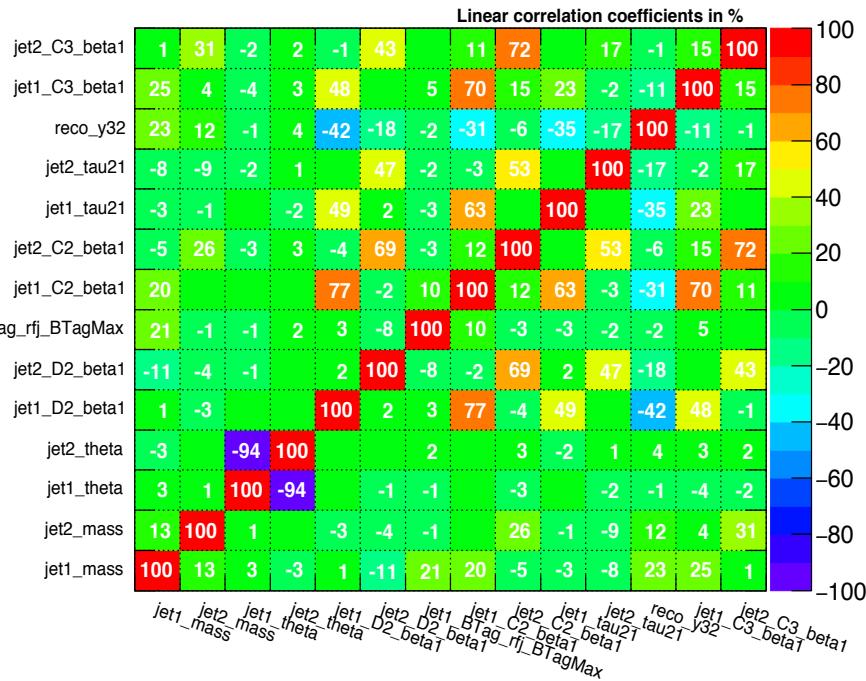


Large correlations between polar angles of both jets (back-to-back)
 Correlations between substructure variables of each jet

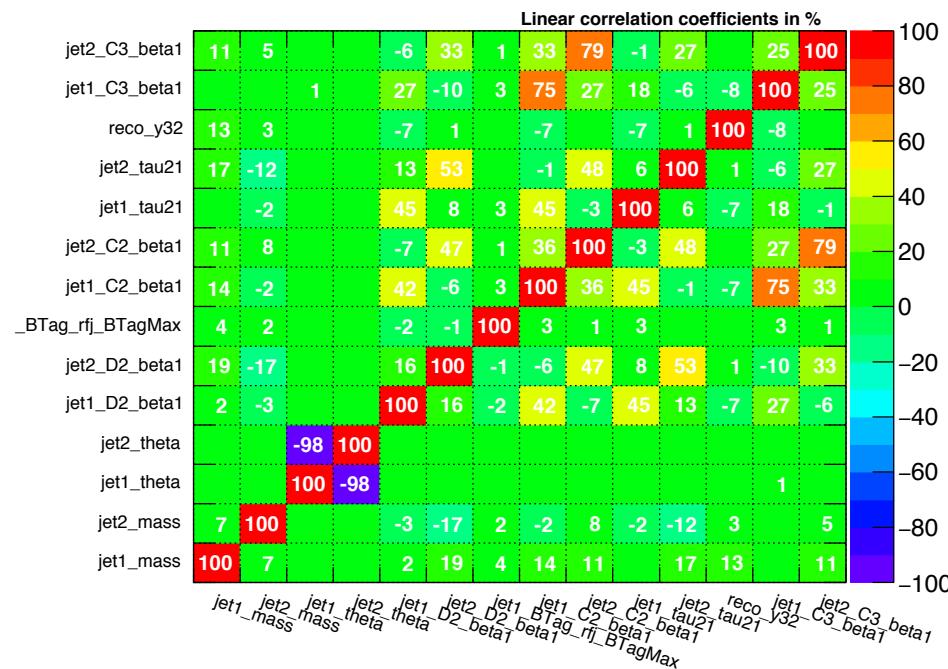
BDT: correlations between input variables: pos pol



Correlation Matrix (signal)

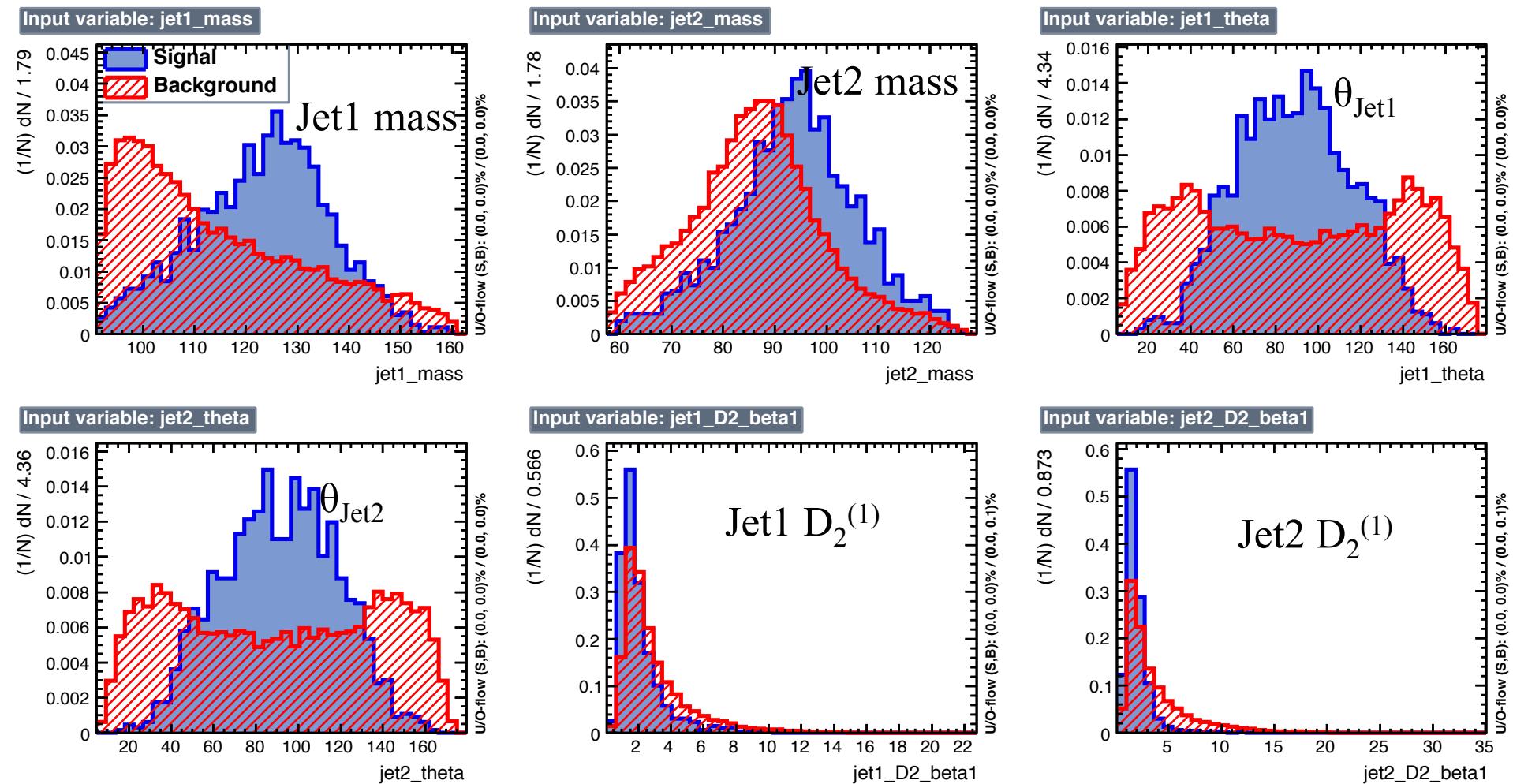


Correlation Matrix (background)



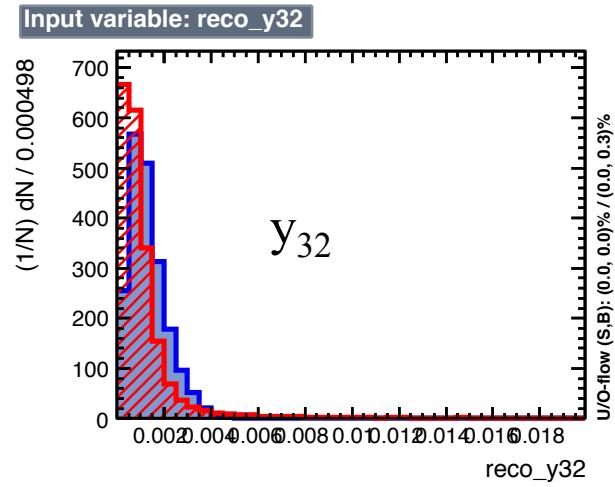
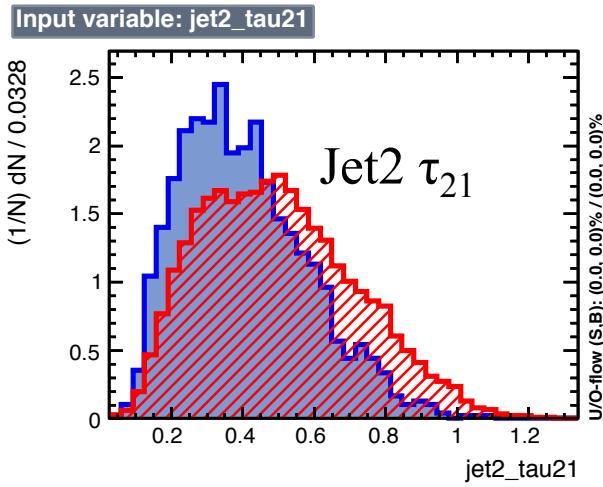
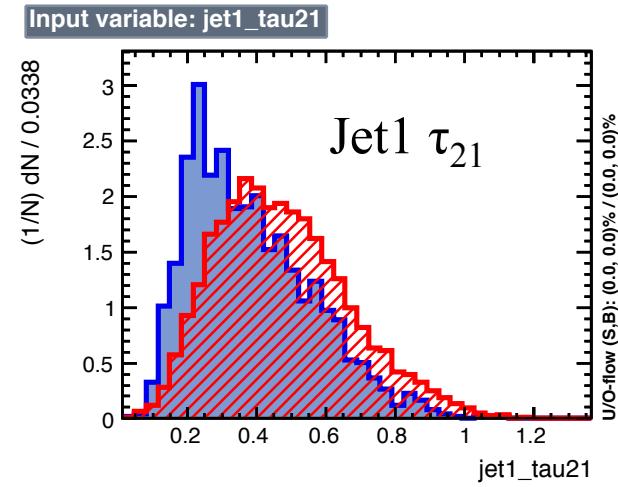
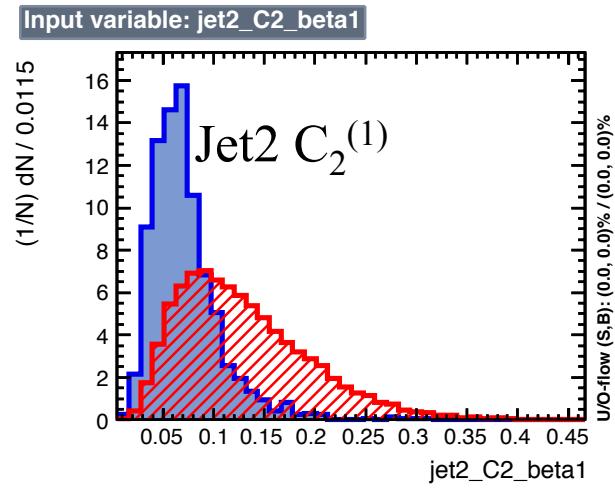
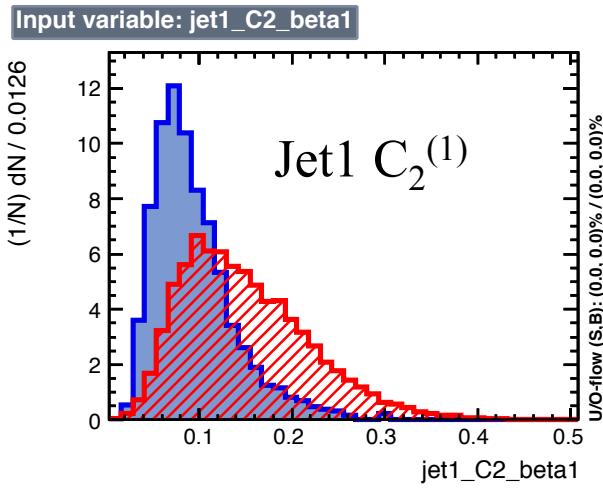
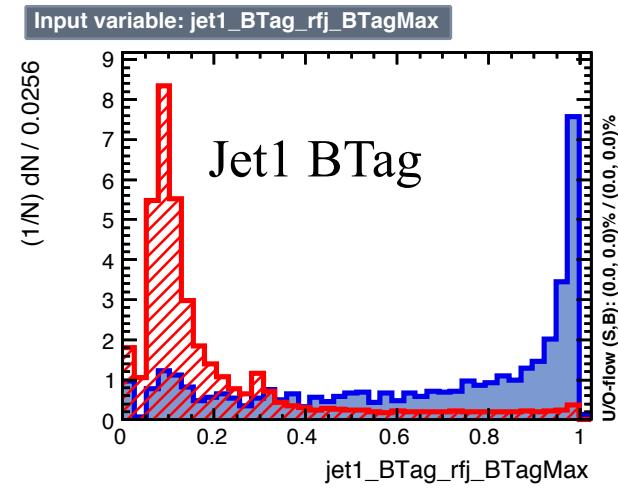
Large correlations between polar angles of both jets (back-to-back)
 Correlations between substructure variables of each jet

Input Variables(1): positive polarisation



Input Variables in boosted decision tree, same input for positive and negative polarisation datasets: jet masses, polar angles, jet resolution threshold y_{23}

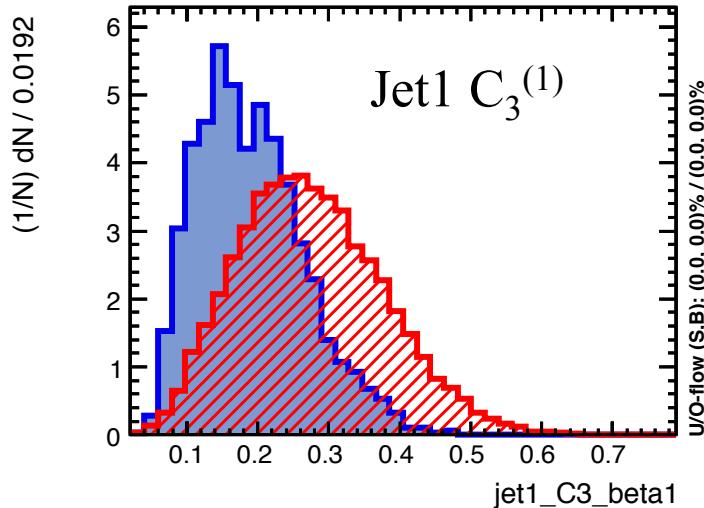
Input Variables(2): positive polarisation



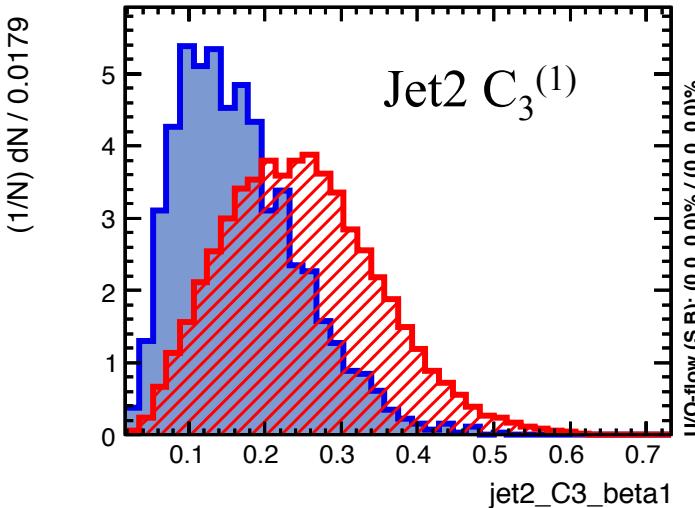
Input Variables in boosted decision tree: substructure variables for both jets τ_{21} , $C_2^{(1)}$, $C_3^{(1)}$, $D_2^{(1)}$

Input Variables(3): positive polarisation

Input variable: jet1_C3_beta1



Input variable: jet2_C3_beta1

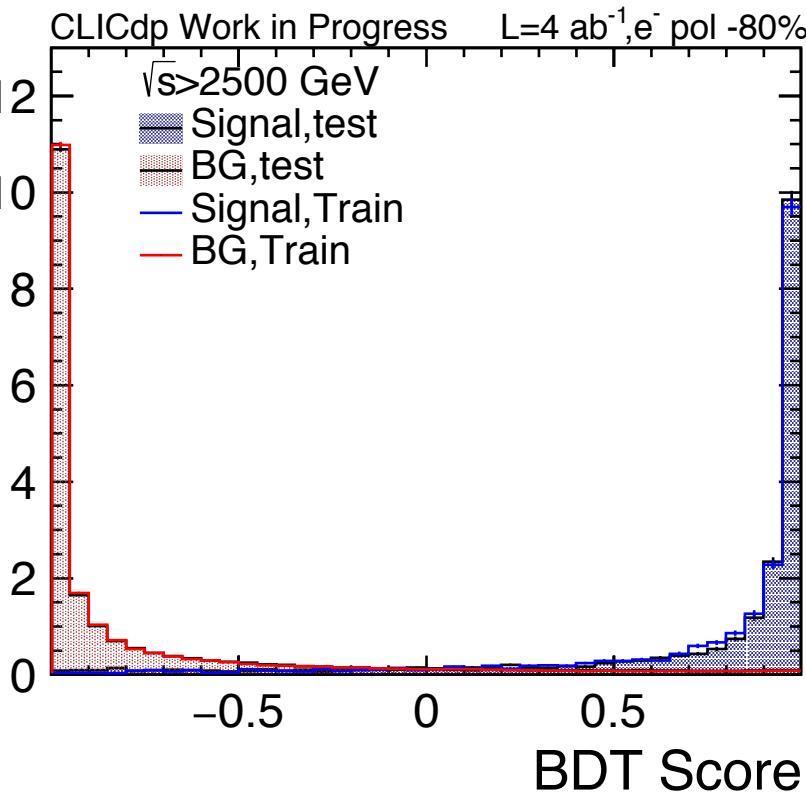


Input Variables in boosted decision tree: substructure variables for both jets τ_{21} , $C_2^{(1)}$, $C_3^{(1)}$, $D_2^{(1)}$

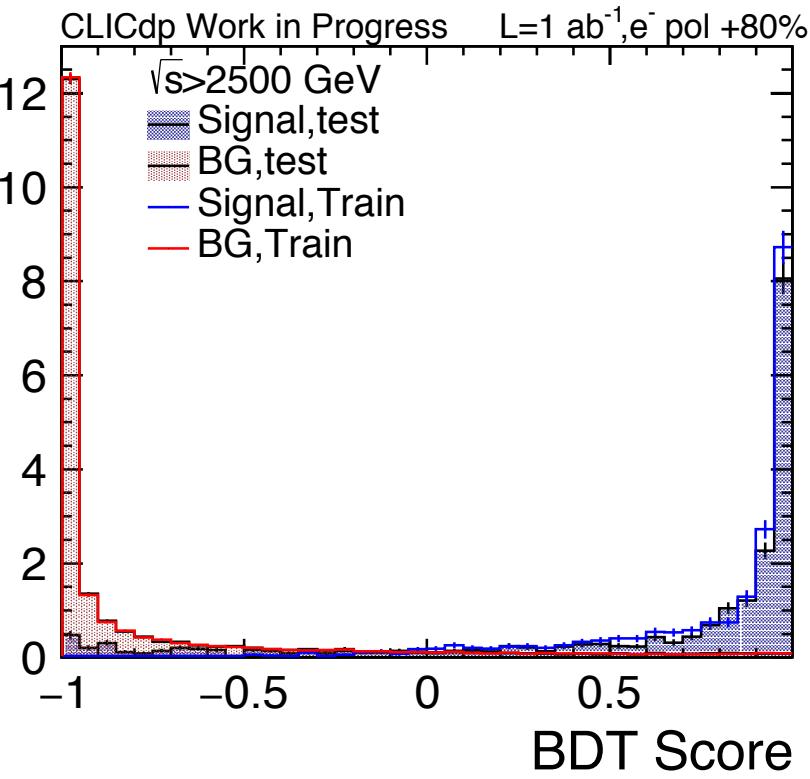
Gradient: BDT-Score for Test and Training Samples



Entries

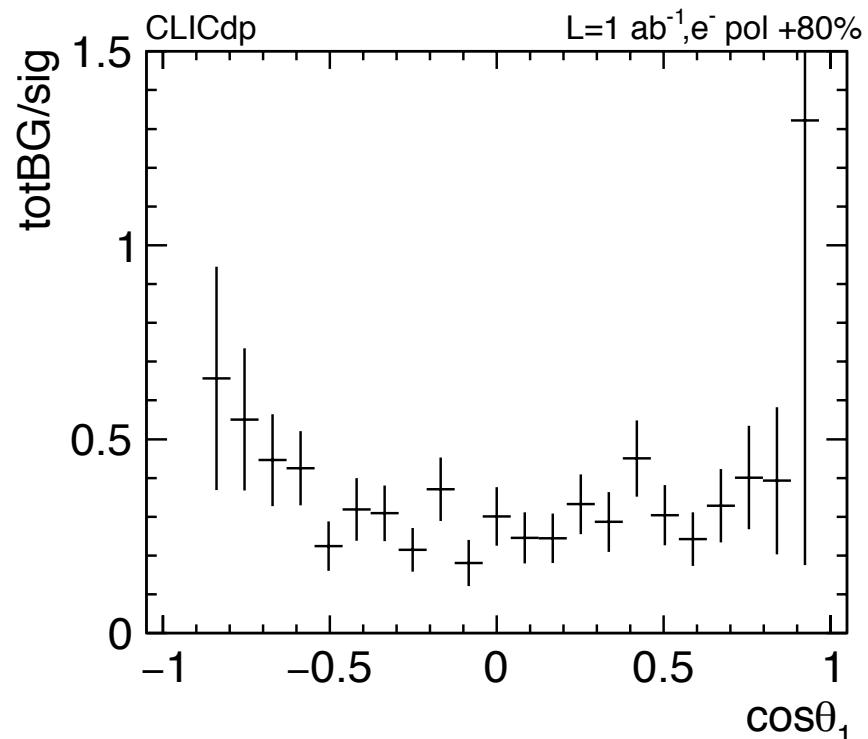
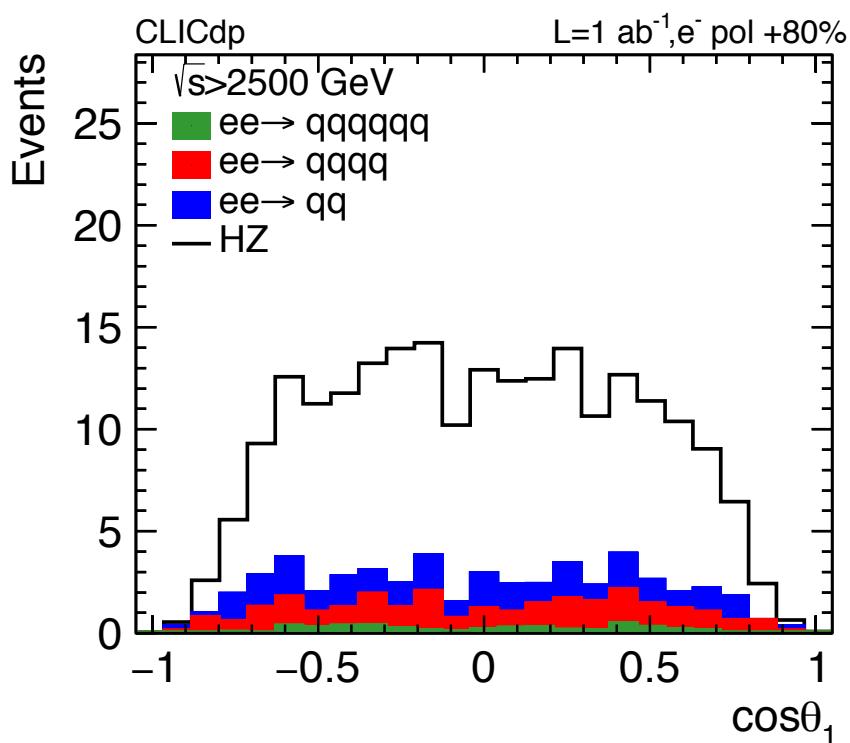


Entries



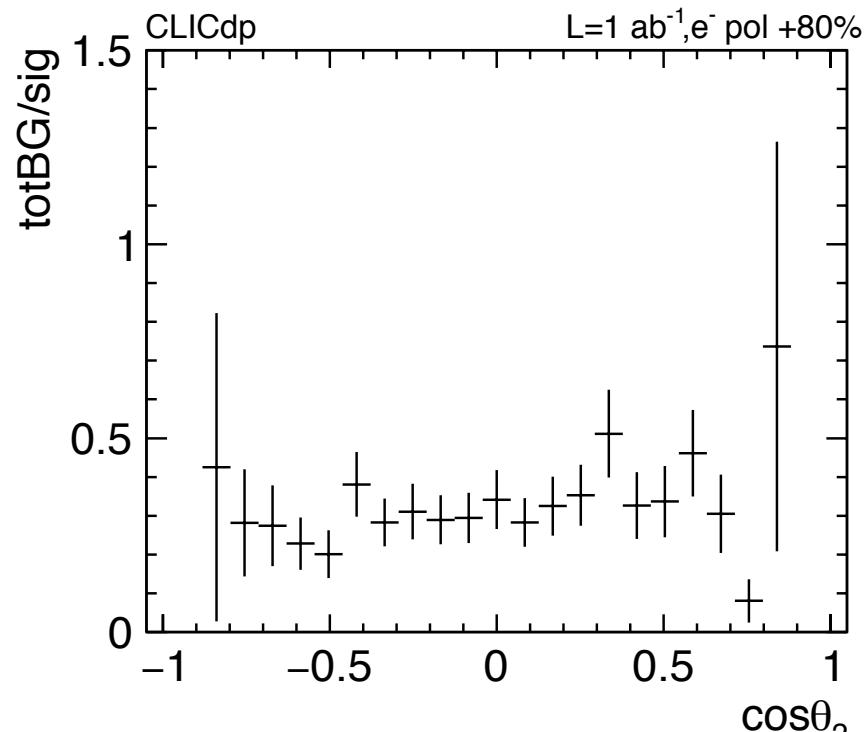
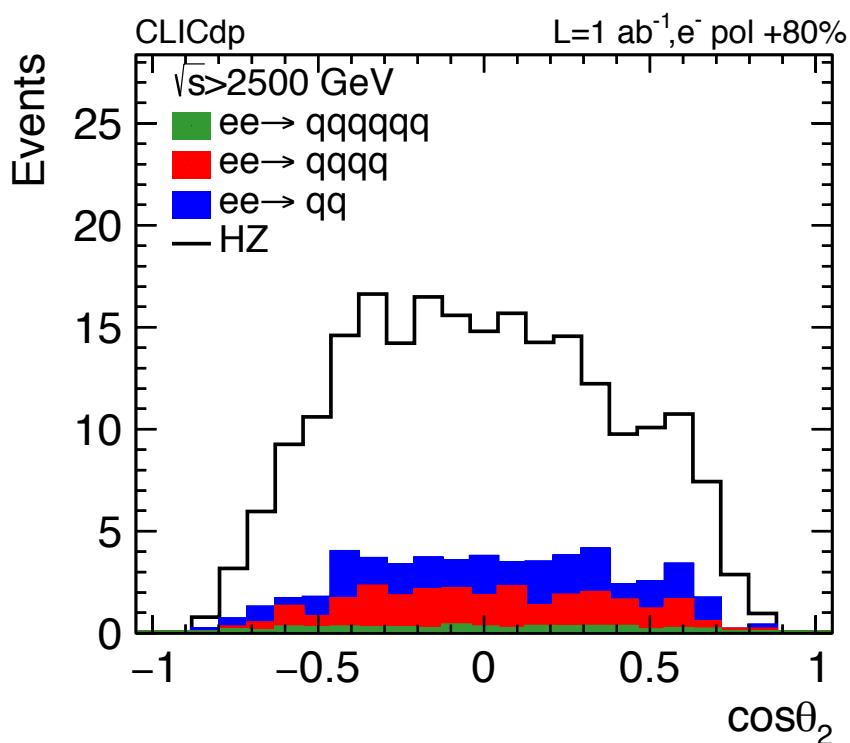
Checked distributions with Shrinkage of 0.75, 1.00 and 1.25 → behavior in significance and purity similar, agreement of BDT Score between training and testing events for positive polarisation slightly worse than for Adaptive Boosting

$\cos \theta_1$ distribution, positive polarisation



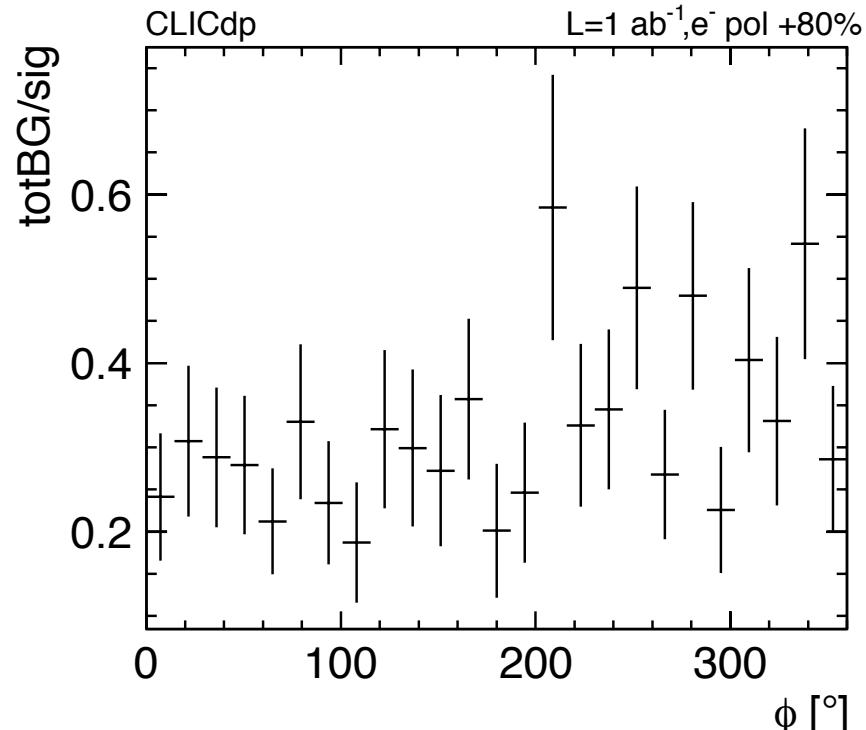
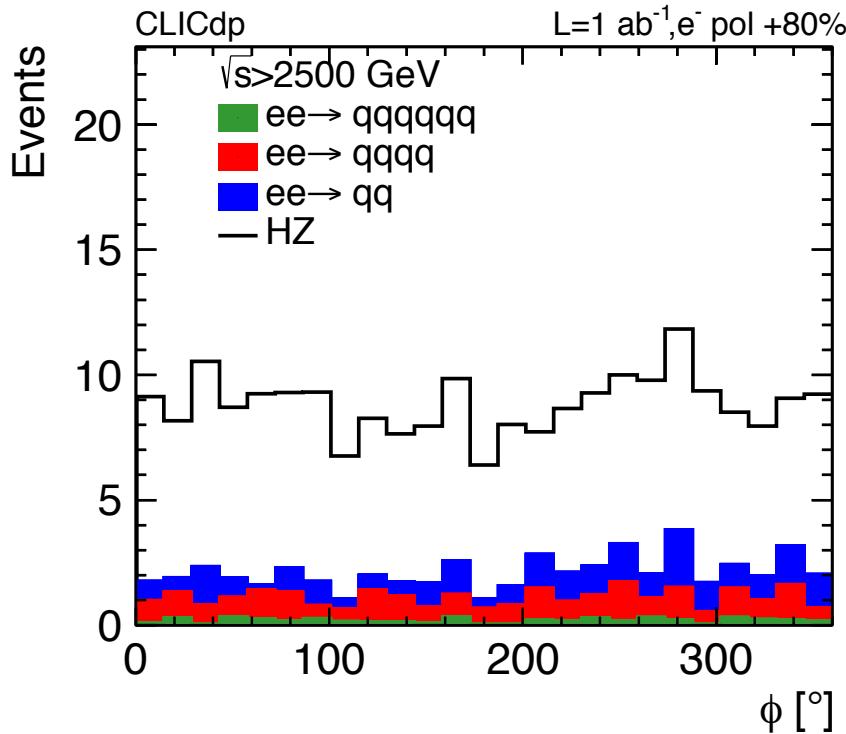
Background distribution not far different from signal distribution for most values (similar for +80% case)

$\cos \theta_2$ distribution



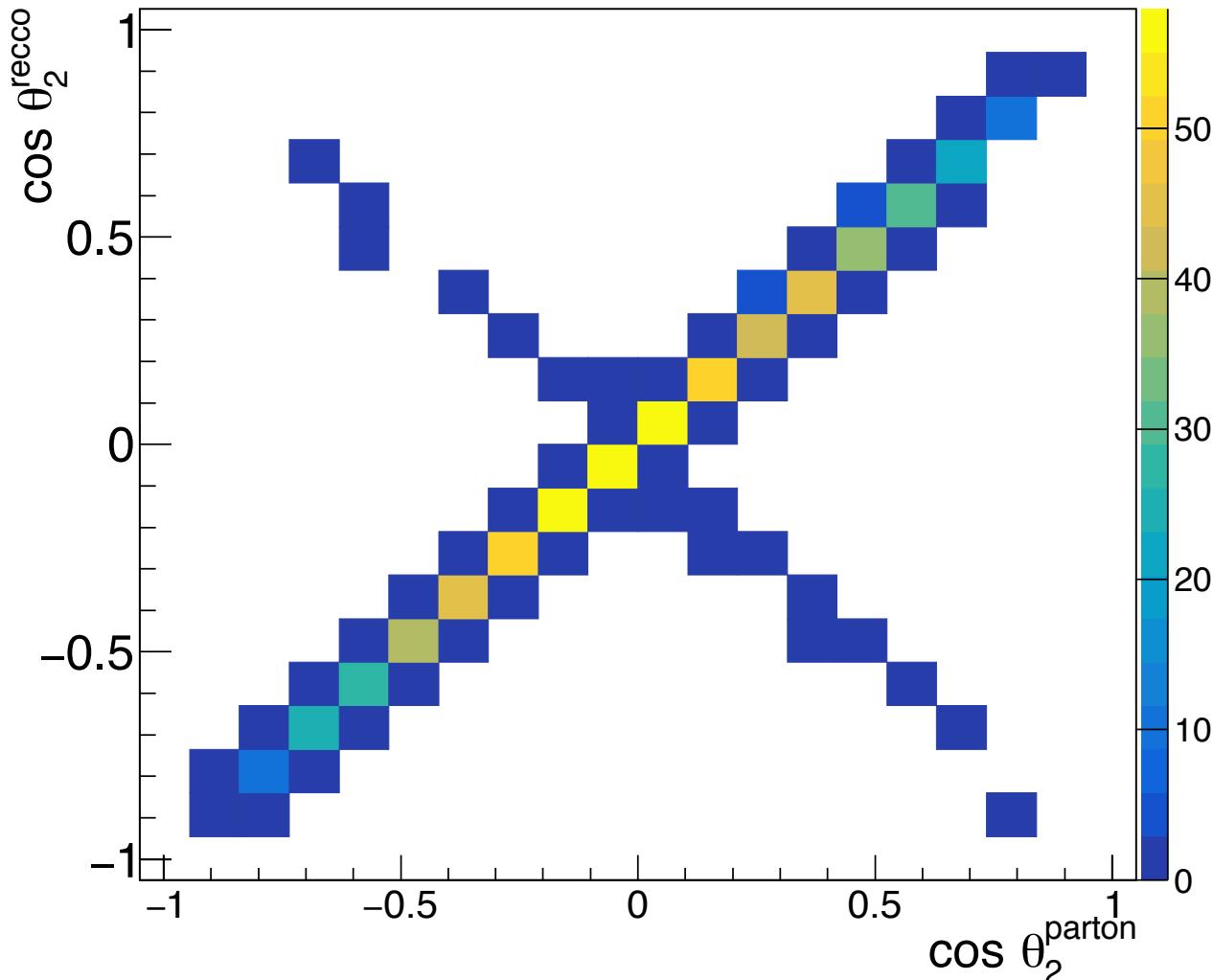
Here use total event energy and p_Z to determine e^+ direction,
ignore crossing angle offset in p_X , less variation between signal
and background shape

Phi distribution, positive polarisation



Rather flat distribution, also background contribution rather flat as well → consider orientation of positive quark with respect to normal vector of H-e⁺ plane

Unfolding Matrix example: $\cos \theta_2$



Diagonal elements clearly dominate, overwhelmingly correct assignment of H-jet,
angular resolution of jets very precise at large energies